NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION

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RTO AGARDograph **AG-SCI-089**

Flight Testing of Night Vision Systems in Rotorcraft

(Test en vol de systèmes de vision nocturne à bord des aéronefs à voilure tournante)

This AGARDograph has been sponsored by SCI-172, the Flight Test Technical Team (FT3) of the Systems Concepts and Integration Panel (SCI) of the RTO.

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RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

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- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

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Nomenclature

ADS-33	Aeronautical Design Standard
AETE	Aeronautical Engineering and Testing Establishment
AGL	Above Ground Level
AHO	Above the Highest Obstacle
ANVIS	Aviator Night Vision Imaging System
AOB	Angle of Bank
CONOPs	Concept of Operations
CRT	Cathode Ray Tube
DIMSS	Dynamic Interface Modelling and Simulation System
DZ	Designated Zone
EEG	Electroencephalogram
FOR	Field Of Regard
FOV	Field of View
Ft	Feet
FTE	Flight Test Engineer
GVE	Good Visual Environment
HMD	Head Mounted Displays
HQR	Handling Quality Rating
HUD	Heads Up Display
IFR	Instrument Flight Rules
IGE	In-Ground-Effect
IMC	Instrument Meteorological Conditions
IR	Infrared
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LLTV	Low Light Level Television
L_{max}	Maximum Luminance

L_{min}	Minimum Luminance
LZ	Landing Zone
m^2	Meters Squared
MTF	Modulation Transfer Function
NASA TLX	National Aeronautics and Space Administration – Task Load Index
NATO	North Atlantic Treaty Organisation
NR_B	Night vision radiance for class B NVG filters
NRC	National Research Council
NVGs	Night Vision Goggles
NVIS	Night Vision Imaging System
OGE	Out-Of-Ground-Effect
OMNR	Ontario Ministry of Natural Resources
PRSA + V	Automatic Flight Control Systems And Visual Cueing
PVC	Polyvinyl Chloride
Rad Alt	Radio Altimeter
RPM	Revolutions per Minute
SAR	Search and Rescue
UCE	Usable cuing environment
USAF	United States Air Force
VA	Visual Acuity
VCR	Visual cuing ratings
VMC	Visual Meteorological Conditions

Preface

Dr. Gregory Craig has a PhD in human visual perception (psychology) from Carleton University in Ottawa. He is a human factors researcher at the National Research Council of Canada, specializing in advanced display and cueing systems for fixed and rotary wing aircraft. He has conducted over 600 hours of helmet mounted display, head down display and night vision goggle flight testing.

Dr. Todd Macuda has a PhD in Neuroscience from the University of Western Ontario and has examined changes in basic visual perception with pilots using night vision goggles in low level helicopter flight. Dr. Macuda has conducted several NVG research projects for military, law enforcement and forestry management applications. Dr. Macuda is also actively conducting research on pilot brain activity during flight manoeuvres using a neural recording system.

Sion Jennings received an M.A.Sc. in Systems Engineering and is a human factors engineer at the Flight Research Laboratory of the National Research Council of Canada. His research has included the integration of advanced display systems, enhanced visual imagery (infrared and mm-wave), and pilot-vehicle interfaces to enhance pilot performance. He is currently active in research on NVG applications, helmet mounted displays and heads-up displays in civilian and military applications.

Major Guy Ramphal has a B.Sc. in Industrial Engineering from the University of Toronto and a Master of Flight Test Technology from the National Test Pilot School in Mojave, CA. Major Ramphal is a qualified military test pilot and a qualified flight instructor with 3600 hours of flight experience, 400 hours with night vision goggles and 40 hours with helmet-mounted and panoramic night vision goggle systems. Major Ramphal is currently a fixed-wing instructor for the Canadian Department of National Defence at the National Flight Test Center in Moose Jaw, Saskatchewan.

Major Andrew Stewart was an experienced test pilot with the rotary wing of the Aeronautical Engineering and Testing Establishment (AETE) with several (100 – 200) hours of experience flying with night vision goggles. Currently, Mr. Stewart pilots helicopters for an air ambulance company in Alberta, Canada.

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Flight Testing of Night Vision Systems in Rotorcraft

(RTO-AG-SCI-089)

Executive Summary

This AGARDograph presents a general summary of suggested Night Vision Goggle (NVG) testing methods and should be used as a framework for developing airborne and laboratory based experiments to evaluate equipment. While there may be basic NVG test methods that can be applied regardless of the eventual use of the NVGs, some organizations will require specific tests of the equipment representative of the operational environment. An evaluation that involves ground and flight tests is desirable to address specific questions and general use issues, respectively. This approach is important because it extends measurements of device characteristics to real vision and flight performance.

The objective of this document is to provide an inventory of rules, standards, procedures, methods and means needed to test and evaluate night vision systems. It identifies best practice methods from each of the participating countries. This is the first step in synthesizing a standardized test methodology.

In order to meet its objective, the scope of this AGARDograph is limited to the testing of night vision devices based on image intensification technology. It does not cover other systems such as thermal imaging, infra-red (IR), millimetre wave radar and low light level television (LLTV). It extensively covers the test methodologies currently used by NATO countries to evaluate night vision systems. It also discusses specific system test methodologies relating to rotary wing aircraft.

This AGARDograph includes sections covering the basic theory of the systems in use today, human vision and its relationship to the technology, general flight test methodology and an inventory of flight test techniques from NATO countries. Some consideration is given to the testing required as a precursor to flight test such as mock-up trials, simulation and aircraft ground trials. However, tests focused on health hazards, ballistic protection, acoustic protection, laser protection and the fitting and wearing of the helmet are not covered. The AGARDograph addresses the influence of NVGs on human visual perception and does not consider other sensor modalities (e.g. auditory or tactile) or aeromedical factors (e.g., neck strain, visual adaptation, eye strain, fatigue, etc.).

Test en vol de systèmes de vision nocturne à bord des aéronefs à voilure tournante

(RTO-AG-SCI-089)

Synthèse

Cet AGARDographe présente un résumé général des méthodes recommandées de test des Jumelles de Vision Nocturne (JVN) ; il devrait servir de cadre au développement d'expériences en vol et en laboratoire pour évaluer les matériels. Alors qu'il peut exister des méthodes de base pour tester les JVN, que l'on applique sans tenir compte de l'utilisation possible des JVN, certains organismes auront besoin de tests spécifiques représentatifs de l'environnement opérationnel. Une évaluation par des tests en vol et au sol est souhaitable pour poser les bonnes questions et résoudre les problèmes généraux d'utilisation. Une telle approche est importante, car elle étend la mesure des caractéristiques du dispositif à la vision réelle et aux performances en vol.

Le but de ce document est de fournir un inventaire des règles, normes, procédures, méthodes et moyens nécessaires pour tester et évaluer les systèmes de vision nocturne. Il identifie les meilleures pratiques de chacun des pays participant. Il s'agit d'une première phase de synthèse d'une méthodologie normalisée de test.

Pour ce faire, le domaine de cet AGARDographe se limite au test des dispositifs de vision nocturne à amplification de lumière. Il ne traite pas des autres systèmes : imagerie thermique, 'infrarouge (IR), radar à onde millimétrique ou télévision à bas niveau de lumière (LLTV). Il traite extensivement des méthodes de test actuellement utilisées par les pays de l'OTAN pour évaluer les systèmes de vision nocturne. Il traite également des méthodologies de test particulières aux aéronefs à voilure tournante.

Cet AGARDographe contient des chapitres couvrant la théorie de base des systèmes utilisés à ce jour, la vision humaine et ses rapports avec la technique, la méthodologie générale d'essai en vol et un inventaire des techniques des essais en vol des pays de l'OTAN. Il est aussi question des tests de « pré-vol » comme ceux effectués sur des maquettes, en simulation et sur les aéronefs au sol. Toutefois, les tests concernant les dangers pour la santé, la protection balistique/acoustique/laser, l'adaptation et le port des casques ne sont pas traités. L'AGARDographe traite de l'influence des JVN sur la perception visuelle humaine et ne prend pas en compte les modalités des autres capteurs (ex.: auditifs ou tactiles) ou les facteurs aéromédicaux (ex.: torticolis, accommodation, ophtalmie, fatigue, etc.).

Chapter 1 – INTRODUCTION

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Over thousands of years of evolution humans have developed exceptional photopic or day vision, but have a somewhat less sensitive scotopic or night vision system. While some animals, such as cats, have improved night vision through the evolutionary development of a tapetum (a reflector which directs more light toward the retina), humans have opted for a technical solution by creating image intensification systems, or Night Vision Goggles (NVGs). NVGs have been particularly helpful in improving night flight operations. However, they do not yet provide field of view, resolution, colour and dynamic range equivalent to full normal day vision. As a consequence, engineers and scientists (both human factors specialists and physicists) have focused their efforts on developing NVGs that provide good image quality and a more realistic view of the world at night. The requirement to operate millions of dollars of air assets safely and efficiently at night has driven a significant number of advances in the field.

Research and development has produced the current state-of-the-art NVG systems with extensive capabilities in key visual performance areas:

1) Reduced electro-optically produced noise, or grainy image display at low illumination levels;
2) Halo reduction, and better imagery in urban environments;
3) Visual acuity or resolution approximating the limits of the human eye and delivering nominal resolution values of 20-20;
4) Contrast sensitivity performance, is less affected at low light levels contributing to an expanded dynamic range and enhanced image detail; and
5) Field-of-view (FOV)-traditional aviator systems offer a 40 degree FOV, while newly developed panoramic NVGs have expanded the FOV to nearly 100 degrees.

The development of smaller/lighter tubes has resulted in the development of a system with expanded FOV. Such a system produces less neck strain for the user because the centre of gravity is distributed and less visual scanning is required. As a consequence, pilots have a significantly enhanced visual flight environment. The current level of performance and image quality delivered by state-of-the-art direct view systems is exceptional, and further enhancements will be made within 5 to 10 years. In addition, reduced weight, lower power consumption and enhanced durability are on the very near horizon for these systems. Although this technology is improving it will be necessary to expand research and development efforts to incorporate new technological advances. The key strength of this well developed field of research is that a well developed nomenclature of engineering specifications of device characteristics exists (e.g. see Mil Std 3009). Militaries from NATO countries select their night vision technologies on the basis of these engineering specifications. These specifications are then used to predict visual performance when using NVGs. This was an accepted standard until a more unified approach towards NVGs was initiated in which

the importance of human factors and vision studies of how NVGs affect visual performance were acknowledged. As a consequence, a breadth of NVG studies has developed; demonstrating the need to provide behavioural specifications of NVG system performance. Although the methodologies for investigating the impact of NVGs on visual performance are not standardized, the general thrust of this emerging field should be to use a unitary approach towards the investigation of the perceptual effects of NVGs that includes both laboratory experimental methods and flight test methods.

This AGARDograph presents a general summary of suggested methods and should be used as a framework for developing airborne and laboratory based experiments to evaluate equipment. While there may be basic NVG test methods that can be applied regardless of the eventual use of the NVGs, some organizations will require specific tests of the equipment representative of the operational environment. An evaluation that involves ground and flight tests is desirable to address specific questions and general use issues, respectively. This approach is important because it extends measurements of device characteristics to real vision and flight performance.

The objective of this document is to provide an inventory of rules, standards, procedures, methods and means needed to test and evaluate night vision systems. It identifies best practice methods from each of the participating countries. This is the first step in synthesizing a standardized test methodology.

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Chapter 2 – BACKGROUND AND OVERVIEW OF NVG SYSTEMS

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2.1 NIGHT VISION SYSTEMS PRESENTATION

In order to facilitate the discussion of NVG evaluation, a brief description of the basic NVG architecture is presented in this chapter. This description is meant to be an overview only. For more detailed descriptions of the NVG system, refer to Photonis-DEP (2006) or American Technologies Network Corporation (2006). The following sections will also describe the basic handling and maintenance of the goggles, the effects of lighting and weather on the goggles and some of the basic changes in visual perception when using NVGs. This background information is presented in order to better express the issues related to crafting laboratory and flight tests discussed in the following chapters.

2.1.1 Sensor Unit

The current section presents a pictorial illustration of the basic components of an NVG system. A typical helicopter NVG system is presented below[1].

Figure 2-1, Figure 2-2 and Figure 2-3 show the components of an Anvis-9 assembly. The complete system consists of:

- Neck cord-used as a second method of securing goggles.
- Battery pack:
  - This pack includes a low battery indicator.
- Helmet mount and clip (different mounts and clips for different helmets):
  - This assembly includes a vertical adjustment knob.
- One binocular NVG assembly known as Anvis-9 system. This system has a series of knobs and levers for proper adjustment and fit:
  - For and aft adjustment knob;
  - Eye span knob;
  - Tilt adjustment lever;
  - Objective focus rings-(left and right eye)-these are pinned to prevent over or under focusing errors. These rings do most of the focusing power in a similar fashion to conventional binoculars; and
  - Eyepiece focus rings-These rings refine focus.

[1] Helicopter NVG systems differ from fast jet systems in that the NVG optics are in-line with the tubes rather than having folded optics (to reduce sheering effects on the neck when ejecting from a fast jet).

Figure 2-1: ANVIS 9 Battery Pack.

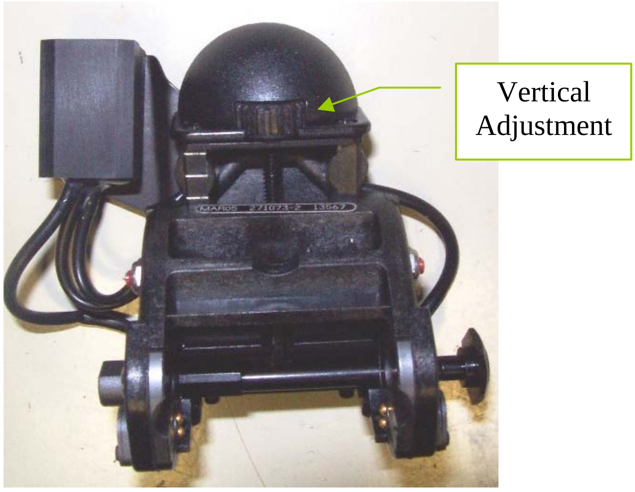

Figure 2-2: ANVIS 9 Helmet Mount and Clip.

Figure 2-3: ANVIS 9 Goggles.

The two basic categories of night vision goggle systems, as per MIL STD 3009, are as follows:

- **"Direct View Image NVIS (Type I).** Any NVIS that uses image intensifier tubes and displays the intensified image on a phosphor screen in the user's direct line of sight."
- **"Projected Image NVIS (Type II).** Any NVIS that uses image intensifier tubes and projects the intensified image on a see through medium in the user's line of sight. This configuration allows simultaneous viewing of the intensified image and visual cues such as HUD symbology."

There are three main components to an NVG – an objective lens, an image intensifier and an eye piece lens system. In basic terms, the objective lens captures the image, which is passed on to the image intensifier. The image intensifier converts the photons into electrons, which are amplified by the

microchannel plate. The amplified image is then converted into photons and imaged on the eyepiece optics for the observer. For other descriptions and illustrations of this process see American Technologies Network Corporation (2006) or Jennings, Craig, Macuda and Erdos (2006).

2.1.2 Understanding the Equipment before Testing: Standard Handling and Maintenance Procedures

The following sections describe basic NVG handling procedures that will help to ensure that the experimenter can set up the goggles in a consistent fashion and prevent damage to the system. These procedures include fundamental actions such as: focusing and adjusting the goggles, cleaning and maintenance.

2.1.2.1 Handling Procedures

The first step in assessing NVGs is a good understanding of proper handling procedures. To use these devices properly in the laboratory, the experimenter should know how the technology is maintained. The following is a detailed description of these handling procedures. Selected sections of the text contained within this section were derived from a Standard Operating Procedure Manual developed by the National Research Council of Canada (NRC) for the Ontario Ministry of Natural Resources (see Macuda et al., 2006a). Readers are also referred to MAWTS-1 (1998). The first step in preparing an NVG system for use is to conduct a thorough inspection of the tubes and the binocular assembly. Ensure that there are no cracks on the assembly and that all knobs are functional. Use a lens pen or Q-tip with methanol to clean the eyepiece and objective lenses so that dirt does not impair a sharp image. Some operators choose to retain a normal lens cleaning cloth (e.g. for glasses) to maintain a clear lens throughout operations. Inspect the battery case and the mount to ensure no cracks or visible damage is apparent. For battery backs inspect for leaking batteries. The battery pack should be firmly affixed to the helmet before the goggles. Use reversed heavy duty Velcro to snap them in place. Check the battery pack and ensure that no LED is showing (e.g. good battery). The power supply is now ready for further adjustments. Remove the batteries from the holder when the system is not in use to prevent damage from battery leakage. While inspecting the tubes set the eye piece focus ring to 0, to make sure no dioptic power (e.g. focus adjustment) is set before starting the focusing procedure (see below).

The mount should slide easily into the helmet clip and lock into place. Ensure that the mount is locked firmly in place before affixing the goggles. A noted operational problem with conventional ANVIS F4949 mounts is that the nylon is susceptible to cracking over time. It is advised that NVG operators maintain spare helmet clips in their inventory to ensure a capacity to continue operations. There are two contacts on the top of the F4949 system, push the tubes into the helmet mount such that these silver electrical contacts are in the slot. Apply pressure to the goggles perpendicular to the helmet clip to connect them in place. Keep the goggles in an upright position so that no current can accidentally reach the tubes under full illumination conditions (e.g. if mounting them in the hangar before a flight). Push the tubes into the mount at a 90 degree angle. Give them a gentle tug at the eye span tuning knobs to ensure they are firmly attached.

2.1.2.2 Focusing and Adjustment Procedures

While focusing and adjustment procedures vary from individual to individual, the following description serves as a basis for conducting these procedures. The easiest way to focus the tubes is by using the stimuli on a Hoffman ANV-20-20[2] or equivalent system. In essence, the Hoffman provides a series of bar charts with equivalent acuity measurements (see above) that function similarly to a Schnellen Eye Chart. Set up the Hoffman 20-20 in a darkened room and adjust the tubes to a proper fit and view. In the absence

[2] See Hoffman 20-20 operator’s manual for details on this device.

of the Hoffman 20-20 or equivalent system, procedures similar to those described below can be employed in the field using objects at a 6 m or greater distance. The US Army has focused tubes extensively without a 20-20. However, the focus obtained using this method may not be as precise as the focus obtained using the Hoffman 20-20. As the majority of laboratory and flight test research requires precise set-up of the goggles in all respects, the Hoffman 20-20 or equivalent system is suggest for NVG system set-up.

As a first step, set the height of the tubes using the vertical adjustment knob on the helmet clip. This will move the tubes up and down to eye level. The tilt switch on the mounting bracket of the tubes can be used to further adjust this eye height. Once the tubes have been fixed at a satisfactory eye height, one can start adjusting horizontal distance between the tubes to correspond to the distance between the observer's pupils (inter-pupillary distance). This adjustment is accomplished by using the eye-span fine tuning adjustment knob on the side of the tubes that will move the left and right tubes in the horizontal direction (e.g. in and out). Adjust the tubes to match the position of the eyes and a single circular view (40 degrees) is seen. It is crucial that the tubes be set to the correct interpupillary distance as an improper set-up will cause the eyes to continually accommodate and verge in an attempt to bring both of the tubes together into one image. This will contribute to eye fatigue and headache and could be detrimental during a flight operation. Adjusting the tubes fore and aft using the dial centered between the tubes will ensure that the goggles are set to the correct eye relief. To ensure a proper eye relief set the distance between the tubes and the eyes such that the instrument panel can be viewed.

The best starting place for focusing the NVG system is to turn the objective focusing rings to the pin stop. This will be clockwise for the right tube and counter-clockwise for the left. The silver pin on the objective focusing ring ensures that the focus of the tubes will not be out of range and is a good starting point for focusing them. The pin location is set using the Hoffman device and an optical tuning device known as an ANV-126 (or an equivalent system). Once the tubes are set in this position the image will be slightly out of focus. Cover one tube with a cap and lower the tubes into the Hoffman 20-20. Start focusing with the left or right tube and work towards the unfocused tube. Since each tube is now slightly out of focus, turn them slightly in the direction opposite to the locking position to coarsely focus them. Use the eyepiece focusing ring to further refine the focused image. Repeat this procedure for the unfocused tube. When first learning to focus NVGs, one should repeat this process a couple of times before starting the flight operation. The 20-20 is a valuable tool to hone focusing strategies and to objectively ensure that the NVGs are correctly focused. It is viewed as critical equipment in focusing and adjusting NVGs for flight.

2.1.2.3 Pre and Post-Flight Checks

Once the tubes are focused, check the displayed imagery for deficiencies and faults. Acceptable faults consist of:

- Black spots: blank dark spots in the displayed image.
- Chicken wire effect: this is a fixed pattern of lines in the display that looks like a series of honeycombs.
- Output brightness variation: slight variation in the display illumination of the NVGs.
- Bright spots in the displayed image.
- Image disparity, distortion.

Unacceptable faults are completely malfunctioning systems where extreme changes in the shading of the display, an edge glow around the displayed image or a flashing, or flickering intermittent operation of the tubes themselves is visible. Tubes functioning in this fashion should be immediately sent for evaluation and maintenance.

2.1.2.4 Cleaning Procedures

Do not submerge the tubes in liquid; to clean the exterior use a damp cloth or methanol wipe. Clean the eyepiece and objective lens with Methanol, or use a lens pen to remove smudges.

2.1.2.5 General NVG Maintenance and Checks

Keep a log book for each set of NVGs in the same way as a log control book for aircraft. Maintain a record of collimation and purge dates for calibrating and certifying the system for flight use. Keep the NVGs in a safe dry secured location. Maintain all the components in their carrying case. It is advisable to maintain a record of battery usage so that extremely fatigued batteries are not used operationally. If unusual deficiencies in the kit are noticed, record the peculiarities with diagrams as required and with a written report.

2.1.2.6 Focusing

NVGs should be focused within a 20-25 to 20-30 range. A Hoffman 20-20 visual test box or equivalent shall be used when possible to ensure that a minimum visual acuity is maintained. Pilots should be trained extensively in the appropriate methods for focusing the goggles. Focusing problems with NVGs are the leading cause of eye fatigue and resultant visual degradation. For extended missions pilots may need a short period to re-adjust focus of their goggles. In addition, acuity can be affected by shifting lighting conditions. As pilots move from rural to urban conditions acuity may increase slightly. In contrast a shift from well lit conditions to poorly illuminated conditions could degrade acuity slightly. These degradations are typically in the 20-30 to 20-40 range and are within acceptable blur ranges. These levels of acuity are adequate to maintain good visual conditions. At lower light levels however, pilots should be cognizant of increased scintillating noise in the goggles which may influence image quality and degrade target recognition slightly. Also, the appropriate interpupillary distance and eye relief should be established before the mission begins. Pilots should be well trained in these adjustment procedures during their requisite NVG training and recurrent training courses. NVGs should be assessed by the operator during the mission planning procedure. If the operator identifies maintenance or other NVG imagery deficits in this pre-flight check phase they should be sent for appropriate maintenance and assessment checks.

2.1.3 Maintenance

While the previous section detailed the basic set up of the goggles for flight, the current section details some of the routine maintenance and record keeping required to keep the NVGs in good working order. Typically this should include nitrogen purging of the goggles and optical collimation (i.e. alignment).

2.1.3.1 NVG Inspection and Maintenance

NVGs should be inspected and maintained every 180 days by an appropriate facility equipped for all levels of NVG maintenance. To maintain NVGs a Hoffman ANV-126 test set or its equivalent should be used. The new digital system is user friendly and prompts the technician through the appropriate assessment and maintenance checks. This maintaining system is used in conjunction with night vision goggles purge kit for the continuing effectiveness of the NVGs.

Regular maintenance and inspections will ensure that they have appropriate collimation (e.g. optical alignment) and are purged (e.g. prevent condensation in changing temperatures). NVGs with noted problems in usage should be checked before this mandated 180-day term.

2.1.3.2 Inspection and Maintenance Record

This record shall be utilized to record information on the use, condition, and maintenance of the Department issued night vision goggles (NVG). This information is collected to keep a historical record of

the utilization and condition of each NVG. Members shall complete the NVG Inspection and Maintenance Record for each use of the NVGs.

The NVG Inspection and Maintenance Record (Table 2-1) shall be used to record all operational hours and any deficiencies that would render the set of NVGs inoperable. The NVG Inspection and Maintenance Record shall be used to record all inspections and maintenance performed by qualified technical inspectors. Instructions on the maintenance record presented in Table 2-1 are listed in Section 2.1.3.3.

Table 2-1: NVG Inspection and Maintenance Record

1. NVG Log Page #		4. Air Section:	
2. NVG Model #		5. Inspection Due (yyyy/mm/dd)	
3. Serial #		6. Total Accumulated Hours:	

PART I – USE/INSPECTION LOG			**PART II – MAINTENANCE LOG**		
7. Date (yyyy/mm/dd):	8. User/Lic#		14. Date (yyyy/mm/dd)	15. Technician/Lic#	16. TI Hrs
9. Fault/Remarks:			17. Corrective Action		
10. When Discovered (circle one): pre-flight in-flight post-flight					
11. Equipment Hours	12. Signature	13. Status	18. Signature		19. Status

PART I – USE/INSPECTION LOG		**PART II – MAINTENANCE LOG**		
7. Date (yyyy/mm/dd):	8. User/Lic#	14. Date (yyyy/mm/dd)	15. Technician/Lic#	16. TI Hrs
9. Fault/Remarks:		17. Corrective Action		

10. When Discovered (circle one): pre-flight in-flight post-flight					
11. Equipment Hours	12. Signature	13. Status	18. Signature		19. Status
PART I – USE/INSPECTION LOG			**PART II – MAINTENANCE LOG**		
7. Date (yyyy/mm/dd):	8. User/Lic#		14. Date (yyyy/mm/dd)	15. Technician/Lic#	16. TI Hrs
9. Fault/Remarks:			17. Corrective Action		
10. When Discovered (circle one): pre-flight in-flight post-flight					
11. Equipment Hours	12. Signature	13. Status	18. Signature		19. Status
PART I – USE/INSPECTION LOG			**PART II – MAINTENANCE LOG**		
7. Date (yyyy/mm/dd):	8. User/Lic#		14. Date (yyyy/mm/dd)	15. Technician/Lic#	16. TI Hrs
9. Fault/Remarks:			17. Corrective Action		
10. When Discovered (circle one): pre-flight in-flight post-flight					
11. Equipment Hours	12. Signature	13. Status	18. Signature		19. Status
			20. Total hours this page:		
			21. New Total Accumulated Hours:		

2.1.3.3 Inspection Record Instructions

This section provides instructions for filling out each part of the NVG Maintenance and Inspection Record presented in Table 2-1. Part I – Use/Inspection Log (blocks 7-13) shall be completed by the end user of reach use of the NVG. Part II – Maintenance Log (blocks 14-19) shall be completed by an authorized technician.

BLOCK INSTRUCTIONS

1. NVG Log Page # – The number of the current page. All pages should be kept as a history of set of NVG.

2. NVG Model # – Model number of the equipment.

3. Serial Number – The manufacturer serial number.

4. Air Section – The section that the NVG is assigned to.

5. Inspection Due – The date of the next required 180 day inspection.

6. Total Accumulated Hours – Enter the figure from block 21 on the previous page.

7. Date – The date of use/inspection.

8. User/Lic# – User identification.

9. Fault/Remarks – If no defects or faults were observed, at the end of the flight enter “Flight OK” in this block. Enter any observed or known defects with the NVGs. If “U/S” is entered in block 13, state the reason for the inoperable status. Operational defects include Shading, Edge Glow, and Flashing, Flickering, or Intermittent Operation.

10. When Discovered – Circle the appropriate time when the Fault/Remark in block 9 was discovered. If “Flight OK” was entered at the conclusion of the flight, circle “post-flt”.

11. Equipment Hours – Enter the hours in use for this entry.

12. Signature – Signature of user.

13. Status – Enter “S” for a serviceable set or “U/S” for an unserviceable set. If “U/S” ensure block 9 is filled, remove the set from service. The NVG is inoperable until and authorized technician corrects the fault.

14. Date – The date of corrective action.

15. Technician/Lic# – Technician identification.

16. TI Hrs – Hours required for corrective action.

17. Corrective Action – description of corrective action taken.

18. Signature – Signature of Technician.

19. Status – After corrective action taken, the technician enters either “S” or “U/S’. Unit must be “S” for a return to operational use. If the goggles are still “U/S”, the technician must determine the next appropriate course of action.

20. Total Hours this page – Enter the total equipment hours (from block 11) for the entire page. Do not include the hours for maintenance (block 16).

21. New Total Accumulated Hours – Add: block 6 + block 20. This figure is the new total and will be carried over to the next page.

2.1.4 The General Effects of Lighting on NVGs

This section of the paper addresses the effects of aircraft internal/external lighting. All laboratory and flight test studies should consider a range of experimental lighting conditions to assess device characteristics. Although lighting conditions in the laboratory can be tightly controlled, care must be taken to ensure that the laboratory lighting conditions are consistent with those found in NVG flight conditions when examining NVG performance. The lighting conditions for flight tests cannot be controlled, but checks of the moon phases, weather and test locations can be chosen to minimize the differences in lighting between flights. The remaining differences in light level can be measured with a radiometer and accounted for statistically, if necessary.

The following sections describe many natural and artificial sources of energy that combine to illuminate the night environment. Natural sources include the moon, stars, solar light and other atmospheric reactions, while artificial sources include city lights, fires, weapons, searchlights and flares. This section describes some of the basic effects of these light sources on NVGs and visual perception (Portions of the following sections are based on Jones and Shwalier, 1998; and MAWTS-1, 1998).

2.1.4.1 Aircraft Lighting

The topic of NVG lighting compatibility is covered in detail in MIL STD 3009 Lighting, Aircraft, Night Vision Imaging System (NVIS) Compatible. Compatible lighting refers to wavelengths to which the goggles are insensitive. These wavelengths do not interfere with the performance of the image intensifiers in the goggles. Incompatible lights refer to wavelengths to which the goggles are sensitive and, in sufficient quantity, the incompatible light will reduce the gain of the goggles. If the incompatible light is coming from the cockpit, the pilot will be unable to resolve much detail outside of the cockpit. In the cockpit, compatible lighting is used to allow the pilots or crew to read instruments, maps, etc., while allowing the pilot and crew to see the external scene. This section discusses NVIS compatibility as it relates to flight test.

NVGs operate by amplifying nearly any existing light, regardless of whether the light comes from the environment or from the aircraft. If there are sufficient sources of NVG-incompatible lights emitted from the aircraft, the gain of the goggles will be reduced. If the gain of the goggles is reduced, particularly by incompatible cockpit lights, the pilot will not be able to see outside of the aircraft. External lights will also affect goggle performance and additionally may affect portions of the exterior view (Figure 2-4) so that the area illuminated by the incompatible light is easily seen, but the areas beyond are difficult or sometimes impossible to see. Figure 2-4 shows the view from the co-pilots seat in a Bell 206, where the incompatible light from the left side position light illuminates portions of the exterior view and engulfs large portions of the pilots view in shadow.

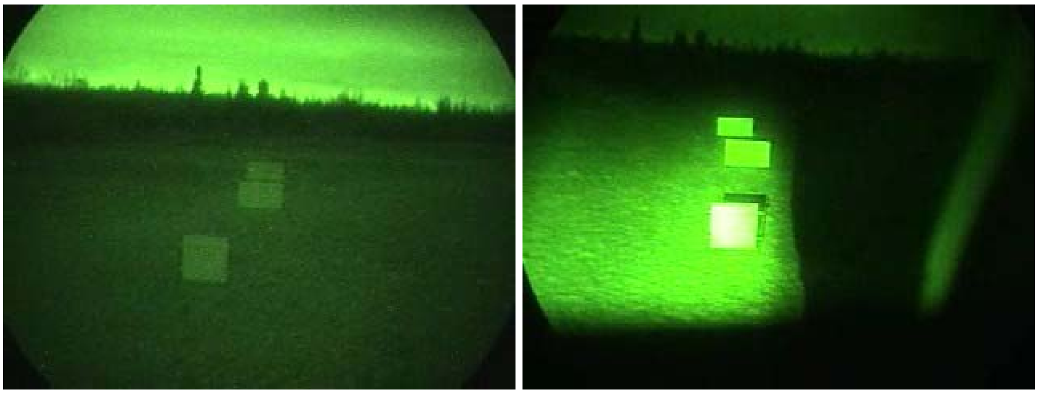

Figure 2-4: Effects of NVG Compatible (left) and Incompatible (right) Lighting.

The key element of NVG lighting, particularly with respect to NVG evaluations will typically be to ensure that the aircraft lighting is compatible with the NVGs being tested. If the lighting is incompatible, the goggles will not function at their highest capacity. For some goggle comparisons, the effects of incompatible lighting on goggle function may be of limited interest in assessing the size of light source halos, blooming, and scintillation.

Evaluation of the compatibility of the aircraft lighting can be done by trained observers/test pilots. The basic elements of the cockpit lighting tests are to determine if there are any areas inside of the cockpit that are poorly illuminated, or areas that are over-illuminated, causing glare that will affect the readability of the displays (see Chapter 3 for a more detailed description of the process). For tests of the external lighting, the pilots will be looking for areas of high brightness contrasts outside of the helicopter, as well as internal reflections and blooming of the goggles. These systems need to be tested in both urban (typically well lit) and poorly lit areas, at high and low altitudes to determine the full range of effects of the lights (if any).

2.1.4.2 Moon

When present, the moon is the primary source of natural illumination in the night sky. The amount of moon illumination reaching the earth's surface is dependent on moon elevation above the horizon (moon angle) and the lunar phase.

2.1.4.2.1 Moon Angle

The moon's angle relative to the horizon determines how much of the moon's illumination reaches the surface of the earth. Illumination from the moon is greatest when the moon is at its highest point (zenith) and at its lowest when the moon is just above the horizon. This effect is caused by absorption of energy as it travels through the atmosphere; at low moon angles there is more atmosphere for the energy to penetrate and hence more energy absorption occurs. Particles in the atmosphere (e.g. rain, fog, dust) will also increase this absorptive effect. An additional problem associated with a low angle moon concerns the adverse effect it has on the NVG image. The bright light source (moon) will degrade the image making it difficult to see terrain detail such as ridgelines. In fact, flying towards a low angle moon results in problems similar to those experienced when flying towards a low angle sun. All these factors should be considered during mission planning.

2.1.4.2.2 Phases of the Moon

Illumination is also affected by the phases of the moon. There are four distinct phases in the lunar cycle: new moon, first quarter, full moon and third quarter. For a period of time during the new moon phase,

the moon face is completely in the earth's shadow (no apparent disk) and is not visible. However, this phase, which lasts about 8 days, also includes periods when approximately one quarter of the moon's surface is illuminated. A relatively low light level is characteristic of the new moon phase. Following the new moon phase is the first quarter (waxing) moon phase. One quarter to three quarters of the moon disk is visible during this phase, which lasts approximately 7 days, and good illumination is provided. The full moon phase covers the period when more than three quarters of the moon disk is visible and lasts approximately 8 days. The third quarter (waning) moon is the last phase and lasts about 7 days. It covers the time period when three quarters to one quarter moon disk illumination is present. Good illumination is provided during this phase, though slightly less than during the first quarter due to the type of lunar surface (mountainous) being illuminated by the sun. The entire cycle is repeated each "lunar month," which lasts approximately 29 days.

2.1.4.3 Shadows

Another characteristic of the changing moon position is shadowing. Moonlight creates shadows during night-time just as sunlight does during the day. Understanding what cannot be seen in night-time shadows is critical to NVG operations. Since they contain little or no energy (and some energy must be present for the NVGs to provide an image), shadows can completely hide obstructions such as ridgelines or towers, and may make it difficult to detect waypoints, targets, LZs, DZs, etc. The term foreshadowing refers to a particular shadowing situation in which near objects may be masked by the shadow created by a distant, higher object. Any of these effects can be a serious threat during low level flight.

2.1.4.4 Stars

The stars provide about 20 percent of the night sky illuminance on a moonless night. They contribute some visible light, but most of their contribution is in the form of near-IR energy. This means the majority of the energy is invisible to the human eye, but is within the response range of NVG image intensifiers.

2.1.4.5 Solar Light

Skyglow is ambient light from the sun that can adversely affect NVG operations up to 1½ hours after sunset and ½ hour prior to sunrise, depending on latitude and time of year. For example, in Alaska skyglow will have a prolonged effect during the time of year when the sun does not travel far below the horizon. Skyglow will affect the gain of the goggles and thus reduce image quality. The effect is similar to flying into a sunset and results in the loss of visual cues when looking either west (sunset) or east (sunrise). Mission planning should take skyglow and its effects into consideration.

2.1.4.6 Other Background Illumination

The greater portion (approximately 40 percent) of energy in the night sky originates in the upper atmosphere and is produced by chemical reaction (ionization) processes. Other minor sources of night illumination are the aurora and zodiacal light caused by the scattering of sunlight from interplanetary particulate matter.

2.1.4.7 Artificial Sources

Lights from cities, industrial sites, and fires are also small sources of illumination. Light from weapon flashes, flares, and explosions can also adversely affect NVG performance, but the effects are usually short lived due to the nature of the source (e.g. short 20ms/30ms bursts). In this case, the goggle image would return to normal as soon as the offending light source disappears.

In the case of incompatible cultural lighting, there are several effects that can occur when looking at street lights, lights from houses, vehicles and even from civilian airport lighting systems. One of the visual

artefacts that arise from NVGs is the formation of halos. Halos are generated during the image intensification process and are seen as bright rings around incompatible light sources, as shown in Figure 2-5. Prior research has showed that halos subtended a relatively constant visual angle on the goggles (1°48’). In practical terms, this means that the halo appears to get smaller relative to the background as the observer approaches the light source. This counterintuitive contraction of halo size with decreasing viewing distance may impact perception of closure rates, and distance estimates to light sources for pilots (Craig, Macuda, Thomas, Allison & Jennings, 2005).

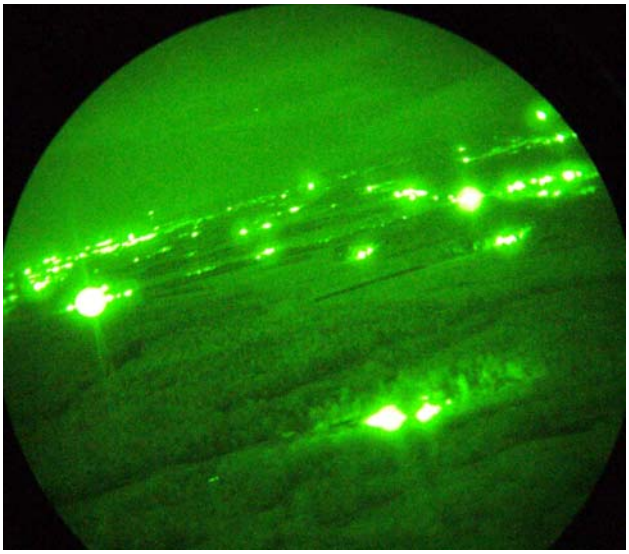

Figure 2-5: NVG Halos Resulting from Incompatible Cultural Lighting.

When viewing incompatible cultural lights through NVGs, the goggles’ automatic brightness control will reduce the gain of the goggles to prevent damage from the bright incompatible lights. When looking in an area with an incompatible light, the reduction in gain in the goggles means that the area around the incompatible light will appear darker. This may make it difficult to detect objects and texture in the NVG image when there are incompatible light(s) in the image. For this reason and others (e.g. effects of halos, potential to damage goggles) looking at areas with incompatible lights for long durations should be avoided when possible.

Can the goggles be used equally well in a well-lit urban area as compared to a rural area with few or no ground light sources? By the same token, can the goggles be used equally well on an overcast starlit night compared to a bright, moonlit night? Although measuring the gain of the goggles and the pilot’s visual acuity through the goggles may begin to answer these questions, a series of short flights under a variety of lighting conditions will better identify some of the potential deficits in goggle performance. In the urban or brightly lit flight conditions, the pilot/observer will be looking for halos, blooming or image loss due to the bright lights. Under very low light levels, the goal is to determine if the goggles have sufficient gain and image intensification to produce an image with enough contrast (and an acceptable level of noise) to distinguish obstacles, terrain, and targets. From a flight safety perspective, it may not be prudent to fly under the lowest levels of illumination in the event that the goggles cannot function well enough, or in the event that conditions worsen to the point that the goggle cannot function at all. An alternative is to fly in well illuminated (in goggle terms) conditions, but to have the evaluator use a set of goggles equipped with broadband neutral density filters to artificially lower the light level. Under these conditions, the safety pilot still operates with a good NVG image, but the evaluator can examine the performance of the test NVGs under lower light conditions.

2.1.5 The General Effects of Weather on NVGs

The following sections will describe some of the fundamental effects of weather on the performance of NVG systems and the NVG imagery. In particular, the minimums for flight are discussed, as well as the effects of clouds, fog, and precipitation.

2.1.5.1 Weather Minimums for NVG Flights

Visibility at or above 3 miles and ceilings at or above 1000 feet are required for all night flights or operations where the minimum allowable altitude for that flight is 500’ based on the crew composition.

Visibility at or above 5 miles and ceilings at or above 1500 feet are required for all night flights or operations where the minimum allowable altitude for that flight is 1000’ based on the crew composition.

The Chief Pilot will assign more restrictive weather minimums than those discussed herein as deemed appropriate. Weather minimums that are more restrictive than these may be adopted on a unit basis when deemed appropriate by the Chief Pilot.

2.1.5.2 Weather and NVGs

Any atmospheric condition which absorbs, scatters, or refracts illumination, either before or after it strikes the terrain, will effectively reduce the usable energy available to the NVG. This reduction, in turn, degrades our ability to see key features critical for flight. The exact amount of reduction is difficult to predict because a common factor cannot be applied to each condition.

2.1.5.3 Clouds

Because of their variability, it is very difficult to predict the effect clouds may have on NVG operations. In general, NVGs easily “see” clouds that are dense, but may not see clouds that are less dense. In the case of the more dense clouds, both visible and near-IR energy is reflected and the NVG can see the cloud (just as you can see the cloud unaided if there is enough light), especially if silhouetted against the night sky. However, dense clouds will reduce the amount of illumination striking the ground and therefore reduce the luminance available for NVG use. Thin (less dense) clouds have more space between their particles. Because the near-IR wavelength is slightly longer, it has a greater chance of passing through these type clouds than does the shorter visible wavelength. It is possible for the thin and wispy clouds (which may be seen with the naked eye during daytime) to be invisible when viewed through the NVG. This potential invisibility is possible given the following conditions:

- The clouds are less dense;
- The clouds are low level, and set in against the terrain rather than being silhouetted against the night sky; and
- Ambient illumination is either very high or very low.

The invisibility of thin clouds can create a severe hazard for NVG operations. Even though a cloud is “invisible,” you may not be able to see the terrain behind it because the cloud reduces luminance, which in turn reduces scene contrast and texture. In turn this may produce a false perception of distance, resulting in the pilot either not seeing the terrain or thinking it is farther away than it actually is. Additionally, the cloud may get progressively thicker, allowing the pilot to progress into the cloud without initially perceiving it or the terrain beyond. If a cloud is detected, the perception may be that it is at a distance.

2.1.5.4 Fog

Fog is another atmospheric condition of concern for the NVG operator. Its effects on goggles are similar to those of clouds, but there is a greater tendency for fog to be less dense and therefore more of a problem.

It is important to know when and where fog may form in your flying area. Typically, coastal and mountainous areas are most susceptible.

2.1.5.5 Rain

Like clouds, the effect rain may have on goggle performance is difficult to predict. Droplet size and density are key ingredients to its visibility or invisibility. Light rain or mist may not be seen with NVGs, but will affect contrast, distance estimation, and depth perception. Heavy rain is more easily perceived due to the large droplet size and energy attenuation.

2.1.5.6 Snow

Snow occurs in a wide range of particle sizes, shapes, and densities. Snow crystals, while small in size, are generally large in comparison to the wavelength of visible light and near-IR energy, and will easily block or scatter those wavelengths. As with clouds, rain, and fog, the more dense the airborne snow, the greater the effect on NVG performance. On the ground, snow has a mixed effect depending on terrain type and the illumination level. In mountainous terrain, snow may add contrast, especially if trees and rocks protrude through the snow. In flatter terrain, snow may cover high contrast areas, reducing them to areas of low contrast. On low illumination nights, snow may reflect the available energy better than the terrain it covers and thus increase the level of illumination.

2.1.6 NVGs versus Unaided Vision

Normal day or photopic vision is very different from the compelling image transformation of NVGs at night. While NVGs provide a green monochromatic image of the world, the NVG image alters the world in a fashion that is sometimes counterintuitive to normal visual experience (Hughes, 2001; Reagan, 2000; Task, 1992). In essence, although NVGs enhance night-vision there are numerous changes in how the visual image is presented to the viewer. The following sections detail some of the known ways in which the NVG scene differs from the normal day vision.

2.1.6.1 Field of View

Humans have a normal binocular field-of-view that is approximately 200 degrees in horizontal extent and 130 degrees in the vertical plane. Visual sensitivity is not uniform over this wide field and tends to be restricted to a 2 degree region known as the fovea. While many visual capabilities (e.g. colour perception, acuity) decline rapidly as distance from the fovea increases the peripheral retina plays an important role in visual perception. For instance, objects viewed in the periphery capture our attention because of their salience, and the eye and head systems work in conjugation to direct the fovea to a target for more detailed inspection. However, one of the most noticeable visual attributes of NVGs is the reduction in visual field from 200 degrees to 40 degrees FOV. With this smaller snapshot of the world pilots are required to make more head movements than normal conditions. In addition, increased head movements and changed scanning behaviour can increase a pilot’s workload (Jennings et al., 1998), but has been suggested as a possible strategy for compensating for reduced field of view. In summary, NVGs alter the visual searching strategy for identifying objects and terrain and a clearly anecdotal preference of helicopter pilots is enhanced field of view.

2.1.6.2 Visual Acuity

Visual acuity refers to the ability to see small details-where “small” means small in visual angle. It is measured in terms of the smallest gap that can be detected by an observer. Typically this is tested with standard targets with a gap between two small dots or two stripes. Obviously bigger gaps are easier to detect (or “resolve”) than smaller ones. “Normal” visual acuity is conventionally defined as the ability to resolve a gap subtending 1 minute of visual angle in targets at all viewing distances from infinity down to 14 inches.

A person who can resolve gaps subtending a visual angle of 1 minute has "normal" visual acuity by definition, and it is expressed as "20-20". If a person can only resolve a 2 minute gap, their acuity is said to be "20-40" since the smallest gap they can resolve at a viewing distance of 20 feet could be resolved by a person with normal acuity at a viewing distance of 40 feet. In general, if the smallest gap that can be resolved is N minutes of visual angle, visual acuity is "20-(N*20)", (e.g. if N = 5 minutes, visual acuity is 20-100.). 20-20 is not the best possible acuity; people with very good acuity can do as well as 20-10 (the ability to resolve a gap subtending ½ minute of visual angle). Visual detail is important in helping us to recognize and identify objects, features and landmarks rather than just allowing us to detect the presence of a feature and object. An enhanced capacity to see detail allows us to see objects at greater distances. In contrast, NVGs slightly degrade visual resolution (Macuda et al., 2005). Current state-of-the art NVGs provide an acuity level of approximately 20-25 or a minimum visual angle of 1.25 minutes under well illuminated conditions. As illumination decreases the acuity provided by NVGs has a resultant decrease. NVGs at night provide significantly better resolution than the unaided eye under night conditions (Bradley and Kaiser, 1994; Hughes, 2001; Hughes et al., 2000; Rabin, 1993; Pinkus and Task, 1998).

2.1.6.3 Luminance Contrast

The way in which we identify borders, edges and junctions in the visual scene and terrain depends on our ability to detect changes in luminance contrast. Changes in shading and luminance contrast are a strong visual cue for determining depth and spatial variations in a scene. Our ability to detect contrast changes as a function of spatial frequency. The optical and electro-optical components of NVGs combine to degrade contrast across all spatial frequencies. Moreover, NVGs tend to exacerbate contrast decrements at high spatial frequencies (responsible for more detail) and a subsequent loss of detail may be noted. In lay terms the consequences of reduced luminance contrast while wearing NVGs may cause a reduced capacity to detect terrain features in shadow, and distinguish low contrast ridges against a sky background. The reduced luminance contrast of NVGs may decrease the capacity to detect targets. It is generally accepted that accurate recognition and identification of scenery requires a broad range of spatial frequencies, if these are reduced or impaired in some ways the capacity to rapidly conduct scene recognition may be reduced. Pilots should be cautious of this effect when following complex scenery and imagery produced by NVGs (Hughes, 2001; Hughes et al., 2000).

2.1.6.4 Stereopsis-Depth Perception

There are many cues in the environment that allow a pilot to perceive the distance and layout of objects and features. Monocular depth cues include the appearance of overlapping objects, perspective, contour, and motion parallax in which more distant objects appear to move slower than objects near to the observer during self-movement. Binocular cues include stereopsis and ocular convergence. Stereopsis refers to the visual image that is produced by two different viewpoints obtained by our two eyes. The difference in these viewpoints allows the brain to calculate the distance to objects and features. Stereopsis is a strong visual mechanism that allows us to interact with the shape and contour of objects near by and those more distance. It is one of the fundamental components of our capacity to detect the depth of objects in the visual scene. NVGs are thought to slightly degrade stereopsis. On current Anvis-9 systems this effect is barely perceptible; however, pilots should utilize all depth cues maximally while conducting low level night flight and landings (Hughes, 2001; Hughes et al., 2000).

2.1.6.5 Chromaticity or Colour

Most humans possess normal colour vision. Colour vision is thought to be an important visual attribute that contributes to our capacity to recognize objects. In some cases it is a salient cue that attracts attention and improves our visual search for objects. We are well exposed to coloured scenes in our normal daily lives. NVGs change this scenery significantly by providing a monochromatic image due to the P-43 phosphor used in the display system. Recent evidence suggests that it is harder recognize monochromatic

objects than it is to recognize coloured objects. As a consequence when conducting searches with NVGs, object recognition may take longer and search duration may be greater than day operations (Hughes, 2001; Hughes et al., 2000).

2.1.6.6 Accommodation and Focusing

The human visual system easily shifts focus between near and far objects by changing the shape of the lens on the eye. Accommodation refers to this shift in lens shape to provide crisp visual imagery during the day. For any particular distance from an object, accommodation is closely linked with the convergence of the eyes and the pupil diameter. In essence, the human visual system continually refocuses itself based on viewpoint. NVGs are a slightly different system in the sense that objective lens of the NVGs are focused at one distance. This tends not to be too much of a problem because aircrews look outside of the cockpit towards distant objects. In addition, the depth of field of these objective lenses allows a broad range of focus for a range of viewing distances. NVGs also comprise two eyepiece lenses that allow observers to see a phosphor image at a very short viewing distance to the eyes. To properly view an image both the objective lens and eyepiece must be focused appropriately. While it is intuitively obvious that appropriate focusing is easy in NVGs, without adequate training and experience and proper focusing stimuli (e.g. Hoffman ANV-20-20), focus errors can occur. The result of a somewhat blurry or defocused image is that the natural optics of the eyes will try to accommodate and bring the image back into focus. If this has to be maintained for long periods of time it can contribute to symptoms of ocular fatigue (e.g. clinically known as asthenopia), reduced visual resolution, and a constant shifting in the verged position of the eyes. As a consequence, the workload to the visual system increases and the degree of visual discomfort may also increase. The overall noticed impact of this enhance workload will be headaches and visual fatigue (Hughes et al., 2000).

2.1.6.7 Distance Perception and Size Constancy

Helicopter pilots frequently use the distance and size of objects to make judgements about the terrain and 3D shape of an environment. For instance, the height of lamp posts and trees can be an important cue during low flying. Pilots may also estimate the size of landing pads from a distance to determine a safe landing. In addition safe hover and flight in a confined area involves the pilot determining the distance and clustering of trees and objects in proximity to their aircraft. Size and distance are also valuable cues when flying in formation. Recent evidence suggests that NVGs may affect our capacity to determine size and distance (Niall et al. 1999; Zalevski et al., 2001). These reports suggest that size constancy and distance perception may be degraded while wearing NVGs. While the magnitude of these decrements may be small, the overall implication is that three dimensional vision with NVGs is different to normal unaided vision. This could confuse the spatial arrangements between objects and pilots should be aware of this impact while conducting night flight operations (Hughes, 2001; Hughes et al., 2000).

2.1.6.8 Motion Perception

Motion perception is a critical visual mechanism when flying. For example, motion in depth is an excellent cue to determining distance of the leading aircraft in formation flight (Hughes, 2001). Hughes and colleagues have shown that the capacity to determine the motion in depth and distance of a leading aircraft in flight is impaired while using NVGs. In addition, NRC has shown that the electro-optical characteristics of NVGs that produce scintillating noise decrease our capacity to detect motion. This impaired motion perception under NVGs suggests that the capacity to detect motion on the ground and fly in formation flight could be affected by NVGs (Hughes, 2001).

2.1.6.9 The Fundamental Paradox of NVGs and Visual Performance – A Summary

The human visual system exploits numerous visual mechanisms to derive cue information and navigate their environment. The preceding discussion addresses several visual mechanisms that could be impaired

while wearing NVGs. While NVGs are a mature technology and an impressive sensor for night flight, they have some adverse effects on the way we perceive the world. Moreover, although NVGs appear to turn night conditions into day conditions almost all aspects of visual performance are degraded while wearing NVGs in comparison to natural unaided day vision. It is important to emphasize that though this technology significantly enhances our operational capability at night, it does not make night into day. All operators should be well versed and briefed on the potential adverse impact of NVGs. In essence, although NVGs allow operational missions that would normally be impossible, operators must be aware of their limitations, and that some things normally easily detectable and recognizable are invisible when wearing NVGs (Hughes, 2001; Craig et al., 2005).

Chapter 3 – LABORATORY SET-UP AND RESEARCH

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3.1 LABORATORY TESTING

Flight testing, while more operationally valid, is typically more expensive to conduct than laboratory experiments. Typical balanced[1] experimental designs can require anywhere from 6 – 50 hours (or more) to conduct. Psychophysical testing is usually an efficient way of evaluating the operators/viewers response to various types of NVG imagery. The tests may involve simple evaluations of pilot visual ability through the goggles or performance of simulated flight tasks with NVG imagery or symbology. These tests are useful in answering specific functional questions about the NVGs under controlled conditions. Often these tests will be useful in determining what sorts of flight tests might be conducted and/or what future laboratory tests may be needed. Alternately, psychophysical tests may be used to further examine some phenomena observed during the flight tests. The following aspects of the psychophysical examination of NVGs are discussed:

- The requirement to develop facilities appropriate for NVGs, which will include well controlled lighting conditions and standard light sources;
- Scientific method or experimental method to evaluate equipment based on optometry, psychophysics, or cognitive research paradigms; and
- Simulator or flight test facilities to assess real operational function.

3.1.1 NVG Laboratory: Dark Room Facilities and Equipment

To conduct precise psychophysical testing, careful control of the testing environment is often required[2]. For NVG testing this entails careful control of the illumination in the test area so that a variety of outdoor night illumination conditions is attainable. By doing so, the performance of the goggles in the laboratory can readily be compared to, or used to predict, goggle performance in the aircraft.

The first step in controlling the lighting in a given area is to eliminate light leaks from outside of the room. This may require plugging small holes and the installation of curtains around doors and windows. Care is needed in choosing material for the curtains as most fabrics show up as "white" in NVGs, regardless of the actual colour of the material. Dark coloured materials such as leather, PVC, latex or similar materials will typically show up as dark under low ambient illumination. The next step is to reduce the amount of reflected light in the room, typically by painting the room with a flat black paint. The purpose of reducing the reflection is to precisely control the overall illumination level from the light source(s) and reflective surfaces will typically increase the ambient illumination level. While any dimmable light source could be used to test the NVGs, a light source which has similar radiant characteristics to those available at night is preferable. Typically the light source radiance characteristics will be matched to those of the moon and the stars, but may also be matched to urban night time lighting radiance characteristics. Fine control of the

[1] In a balanced experimental design all combinations of experimental conditions are tested and compared.

[2] There are a few instances where the ambient lighting, so long as it is consistent between test points, might not influence the experiment (e.g. direct comparison of the performance of different image intensifier tubes), but most of the time the lighting needs to be controlled so that the results of the experiment are relevant to conditions outside of the lab.

level of illumination is also desirable to replicate the wide range of illumination levels available at night. The radiance characteristics provided by the light source will need to be measured usually at the start and end of an experiment because radiant characteristics of the light source will change over time. The illumination level will also need to be measured, particularly if the experiment requires specific levels of illumination (e.g. quarter-moon light). To measure light levels several photometric and radiometric devices are available. However, the unique challenge of NVG research is to characterise light levels in terms of Night Vision Imaging System (NVIS) values. A good standard technology and corporate supplier of equipment capable in this measurement regard is the Hoffman Engineering Corporation. The authors recommend purchasing the Hoffman ANV 410 A and B, for measuring light levels in terms of NVIS and visible light levels, respectively.

The general recommendation of the authors of this paper is to enlist the support of a physicist knowledgeable about NVG function when developing light sources for laboratory use. When selecting light sources for your laboratory, it is important to balance cost with scientific rigour. In many cases funding infrastructure and limitations contribute to a need to use more cost efficient light sources. NRC has opted to use 2856K colour temperature Halogen lamps to be consistent with nominal moonlight and starlight conditions. The design of these systems is based on an original lighting system developed by Alan Pinkus and his research group at Wright Patterson Air Force Base. The main premise of these light sources is that they are a point light source using an aperture to denote illumination intensity without changing colour temperature (RCA Electro-Optics Handbook, 1974). Such a light source provides even lighting to NVGs, preventing variations in the NVG field of view. It can also be used to emulate light levels from moonlight to cloudy starlight. A second alternative approach towards lighting would be to select uniform light sources. These are somewhat more expensive than a point light source, but will provide even better controlled lighting conditions. The Australians have opted for this latter more expensive alternative (Hughes, 2001).

3.1.2 NVG Laboratory: General Experimental Methodology

The basic premise behind any psychophysical experiment is to determine how behaviour (human reaction) is influenced by a prescribed set of condition. In most cases vision scientists conducting NVG work will have a strong knowledge of psychophysical procedures. However, in some cases human factors engineers, while versed in the scientific method and experimental psychology, will be lacking in domain expertise in this area. The authors suggest that in these cases a good working knowledge of psychophysics and human performance measures can be developed through consulting Gescheider (1997) and the AIAA/ANSI Guide to Human Performance measures as an initial starting point. Further, it should emphasized that all NVG and HMD research groups consult the expertise of a trained psychophysicist when conducting laboratory and flight based psychophysical experiments. For NVG testing, the goal is to determine how the subject’s visual perception (and the resultant behaviour) is affected by the goggles. Four general research paradigms can be applied directly to laboratory-based NVG research including:

- Optometry;
- Basic psychophysical methods;
- Cognitive research techniques; and
- Simulation and modelling.

These four approaches are usually blended when conducting NVG laboratory investigations. Frequently, NVG studies have utilized basic optometric assessment techniques such as acuity, contrast, and depth perception to characterise NVG performance[3]. Acuity testing can be used to determine the distance at which an object of a given size can be detected (but not necessarily identified). Performing the acuity tests

[3] Colour vision tests, astigmatism, perimetery and other basic vision tests are likely be of limited use in NVG testing.

at different illumination levels will identify how the performance of the goggles may decrease on flights conducted during different moon phases and during different weather conditions (overcast vs. clear). The limitation of basic acuity tests is that only high contrast stimuli are used. In flight, the pilot is often interpreting and attempting to identify lower contrast targets. As such, contrast testing is particularly relevant to NVG flight in determining which objects/obstructions may be difficult to discern. Stereo-depth perception tests may also be useful in determining any deficiencies or changes in depth perception due to NVG optics or due to poor set-up of the goggles by the user. One difficulty with most standard optometric tests is that they are designed for basic unaided visual ability at short distances. However, some of the acuity stimuli, such as Landolt rings (Figure 3-1) and grating acuity stimuli (Figure 3-2) are relatively easy to produce and rescale for larger test distances.

Figure 3-1: Landolt Ring Acuity Test.

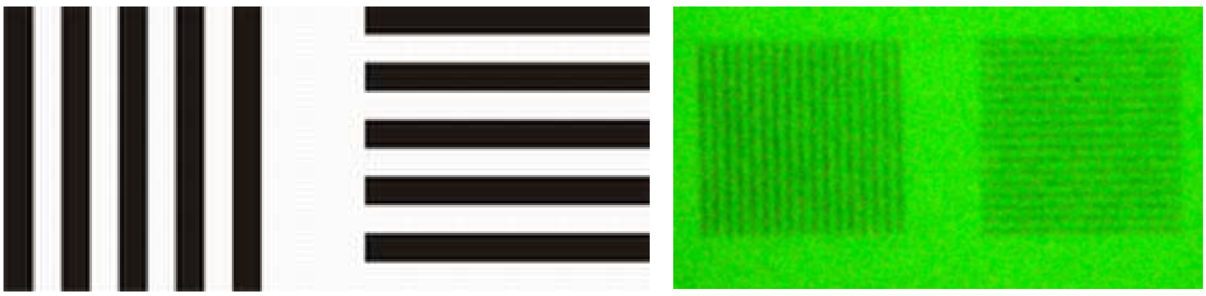

Figure 3-2: Grating Acuity Stimuli (left) and a Sample Seen through NVGs under High Level Illumination (right).

NRC employed some basic optometric tests in conjunction with psychophysical procedures to evaluate different candidate tube technologies for the Canadian Department of National Defence (Macuda, Allison, Thomas, Truong, Tang, Craig & Jennings, 2005). In this test, a comparison was made of subjects' acuity though the different image intensifier technologies at different levels of ambient illumination. The acuity of the subjects using the goggles was assessed via the standard Hoffman ANV-126 and by square wave grating stimuli (see Figure 3-2) that were developed for the test. While these are very basic tests of the NVGs, differences in the performance of the different image intensifier technologies were revealed by both systems. Small differences between the Hoffman ANV-126 and the grating tests were also detected which indicated that the gratings were more sensitive to small changes in acuity than was the Hoffman test[4]. While the optometric tests revealed differences between the tubes in the laboratory, a short flight test was also conducted to gather corroborating test pilot commentary on the performance of the goggles. Although only two pilots assessed the goggles, the salient points of their in-flight commentary mirrored the data that was obtained in the laboratory. This experiment, comprised of both a laboratory and a flight

[4] However, while it is less precise, the Hoffman test is much faster and easier to administer.

test of the NVGs, represents the preferred method of evaluating most cockpit display systems. While much of the precision investigation can be accomplished in the controlled environment of the laboratory, the diversity of conditions existing in real flight may uncover other aspects of the (NVG) system which warrant additional investigation.

Most basic optometric tests are merely simplified and standardized versions of more rigorous psychophysical assessments. Most psychophysical tests involve systematic presentation of a stimulus (e.g. an object that is to be detected) under various conditions such as the level of ambient illumination and/or the rate of motion of the target. Measurements of the subject's response typically consist of determining how accurate the response was or how long it took for the subject to make the response. For example, NRC examined the influence of Night Vision Goggle-produced noise on the perception of motion-defined form using synthetic imagery and standard psychophysical procedures. Synthetic image sequences incorporating synthetic noise were generated using a software model developed by the NRC research group. This model was based on the physical properties of the Aviator Night Vision Imaging System (ANVIS-9) image intensification tube. The image sequences either depicted a target that moved at a different speed than the background, or only depicted the background. For each trial, subjects were shown a pair of image sequences and required to indicate which sequence contained the target stimulus. Subjects were tested at a series of target speeds and at several realistic noise levels resulting from varying simulated illumination. The results showed that subjects had increased difficulty detecting the target with increased noise levels, particularly at slower target speeds. This study suggested that the capacity to detect motion-defined form was degraded at low levels of illumination. The findings were consistent with anecdotal reports of impaired motion perception in NVGs (Macuda et al., 2004, 2005).

There are also assessments of the user's cognitive processes when using the NVG systems. Workload is a general cognitive approach used in most evaluations to determine how easy or how difficult it is to use a given system or how much the pilot needs to compensate for the deficiencies of the NVG system. Workload assessments are discussed in more detail in Chapter 5. Situational awareness is a term for the concept of how and the degree to which the pilots integrate information from themselves, their aircraft and the environment to form an overall representation of their situation and take appropriate action(s) (Endsley, 1993; Endsley, 2000). Assessments of situational awareness may take the form of general questionnaires such as the China Lake Situational Awareness Rating Scale, the Situational Awareness Global Assessment Technique, the Situational Awareness Rating Technique, etc., or indirect measurements of significant aspects of situational awareness. Indirect assessments of situational awareness may gauge the pilot's ability to detect significant information or events, the time it took the pilot to become aware of significant information or how confident the pilot was in their response. The latter tests are typically done in laboratory-based simulation where significant events can easily be programmed to occur during a specified set of circumstances or at specific intervals. Situational awareness questionnaires are often used in both lab and flight settings as they are quick and easy to administer. Applied to NVG testing, the main goal of situational awareness assessments would be to compare the pilot's situational awareness with and without the goggles, with or without the NVG symbology (if applicable), or to determine if there are differences in situation awareness with different types of goggles (e.g. panoramic NVGs vs. normal field of view goggles).

Although many pilots report that NVGs affect situational awareness (Braithwaite et al., 1989, 1998) and spatial navigation few studies have used cognitive methods to address this issue. As an initial approach in this regard, NRC and Carleton University assessed the impact of NVGs on navigation and wayfinding performance and the acquisition of spatial knowledge. Spatial knowledge refers to a mental map or representation of the spatial layout of objects and landmarks in the environment. The methodological approach used two main phases: a learning phase followed by some tests of survey knowledge. Survey knowledge is an image-like representation of the entire geographical area that provides a "bird's eye view" of the environment. In the learning phase, one group of participants was required to navigate a walking maze consisting of 5 rooms with typical household items in each room and locate target objects while

wearing NVGs, while the control group navigated the maze without NVGs. Findings showed that navigation and wayfinding with NVGs appeared to be harder, with longer navigation times and more navigational errors compared to not using NVGs. The impact of NVGs was also evident in spatial memory tasks. Relative direction pointing to targets across rooms and to distracters in the same room was better for those who performed the search without NVGs compared to using NVGs. In a map drawing task, participants in the NVG group were more likely to position objects incorrectly. In addition, NVG users tended to draw maps with an extra room compared to the non NVG group. These results supported the notion that NVGs directly affect spatial navigation and wayfinding performance and the acquisition of spatial knowledge (Craig et al., 2006).

Simulation and modelling are also useful tools in assessing NVG performance under a variety of conditions. Simulation can take many forms ranging from relatively simple mathematical models of image intensifier reaction to stimuli and light levels or full scale motion-base NVG flight simulators. One aspect of NVG simulation that is fairly constant is that often it is the NVG image itself that is simulated. Most simulation displays/screens are not designed to operate at the low light intensity levels that would allow the goggles to be used. One way around this problem is to use a normal CRT or LCD display and put neutral density filters on the NVGs to reduce the amount of light coming into the goggles. The same method can be used to simulate night flight on an aircraft to allow daylight testing of NVG systems. This approach can be particularly useful when attempting to expand the flight envelope of the NVG/aircraft system as it allows the safety pilot to have daylight Good Visual Environment (GVE) visuals while the evaluator flies under NVG imagery. The problem with simulation is that the visuals are different in several ways from what is seen in the goggles during actual night flights. For example, the apparent size and intensity of the halo generated by the NVG in response to an incompatible light source will depend on the intensity and predominant wavelength of the light. In most simulations, the reaction of the NVGs to cultural lighting will be incorrect. While this is relatively unimportant for the effects of street lights and other sorts of urban lighting to be exact, the halos from simulated airport lighting should be accurate. Other aspects of the NVG image such as the noise in the goggles from low ambient illumination, the reaction of the goggles to precipitation, and the inaccurate representation of infra-red content in the image (some of the objects that might appear dark actually appear bright in the NVGs) might also affect the utility of the simulation. However, the greatest advantage of simulation is that the simulation can be changed to be more accurate. One must be careful in planning the type of experiment conducted in a simulation environment to ensure that the simulation itself does not have an undue impact on the results of the study. Finally, it is important to note the operational utility of developing advanced simulated NVG environments. Such simulation and modelling efforts can be used to develop effective NVG trainers. This will allow pilots to maintain perishable skills without the added cost of flight.

In addition to the three blended approaches above, a new methodology for assessing the influence of NVGs on performance is to use aeromedical procedures for monitoring pilot performance. Such assessments include direct measurement of brain activity and other physiological indicators (e.g. eye movements, respiration, blood pressure) in an attempt to link these with behavioural correlates of performance. Until recently, the study of cognitive/perceptual functioning during flight has been limited mainly to simulation or monitoring of behavioural responses. To move towards an augmented cognitive environment in real flight platforms, it is necessary to develop viable airborne test facilities. The importance of developing a cognitive cockpit is that it provides a framework from which to understand the cognitive/neural mechanisms of flight. It will allow an understanding of how display systems and cockpit technologies affect workload and brain function to ultimately reduce the quantity of information presented to pilots. The University of Iowa and NRC are developing a broad research program that will establish airborne neurophysiological and psychophysiological recording facilities capable of monitoring pilot brain activity during flight. A 128 Channel, 128 Electrode, Electroencephalogram (EEG) system (manufactured by Electro-Geodesics Inc.) and related recording equipment are being integrated into fixed and rotary-wing test platforms. The utility of directly measuring pilot state (e.g. brain activity, heart rate) is that it provides an objective measurement of pilot workload and performance decoupled from his/her behavioural

responses. The value of this methodological approach is that it allows NVG evaluators to make inferences about performance and brain activity by directly assessing the human-in-the-loop.

3.1.3 NVG Laboratory: Basic NVG Image Assessments

The quality of the NVG image is a key concern and pilots can readily distinguish a good NVG image from a poor NVG image subjectively. In order to quantify the pilot's subjective assessments of the goggle imagery, a variety of tests can be performed. The fundamental parameters of image quality are assessed in the most basic of tests such as the following:

- Assessment of the signal to noise ratio in at least three light levels;
- Measurement of the Modulation Transfer Function (MTF);
- Checks for the magnitude of imaging defects (white spots, dark spots, shear, gross distortion, non-uniformity); and
- Side effects (halo, coma, veiling glare).

It is important to note that all of these tests should be performed at operationally representative light levels to ensure that the NVG system performs acceptably at each light level. For example, as the gain of the goggles increases, the noise in the goggles will increase, the contrast sensitivity may change, and the ability of the goggles to resolve detail may change.

3.1.4 Measuring Signal to Noise Ratio

The process by which NVGs amplify light, while highly effective, does generate noise in the image. In particular, as the gain of the goggles increases with decreases in the ambient light level, the noise (the number of random transient pixels) in the image increases. Signal to Noise Ratios are typically available from the manufacturer. The authors suggest that experimenters verse themselves with their requisite technological specifications. Alternatively, it is advised to consult a Physicist/Electro-Optics expert to measure these values in situ (see also Lupo, 1972).

3.1.5 Measuring Modulation Transfer Function

The modulation transfer function is the comparison of the contrast of the test stimulus to the contrast of the image on the eyepiece. The test can be done psychophysically by presenting sine-wave gratings (Figure 3-3) of various contrast levels to 3 – 4 observers and determining the contrast threshold level for the goggles. The contrast threshold is the contrast level which the observer can detect 50% of the time. By varying the frequency of the grating presented to the observer, the contrast and resolution of the goggles can be assessed at the same time to determine the "contrast sensitivity function" of the observer with the goggles. The contrast sensitivity function is a plot of the inverse of the contrast threshold by the spatial frequency of the grating. The difficulty with this method is that either a high quality printer or a specialized computer monitor is required to present the gratings without artefacts. There are two alternatives that can provide a somewhat coarser evaluation of the contrast resolving capabilities of the goggles. The first is the contrast ring (Figure 3-4) on the Hoffman Engineering ANV-20/20 can be used to identify the level of contrast visible in the goggles. The subject identifies the segments of contrast that can be seen with the goggles under the normal and low light settings on the ANV-20/20. A good NVG system should be able to resolve all the contrast segments at the normal lighting setting on the ANV-20/20, and only the first three or four segments under the low-light setting (Hoffman Engineering, 1997).

Figure 3-3: Typical Sine Wave Gratings for Testing Contrast.

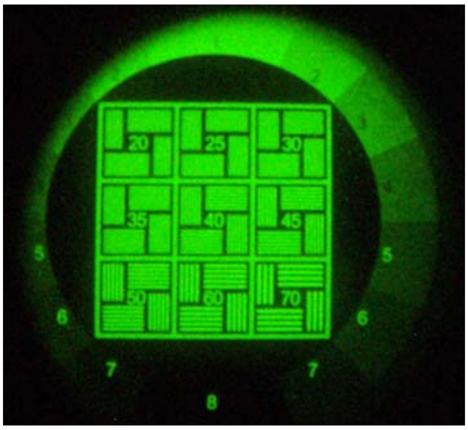

Figure 3-4: Hoffman ANV-20/20 Contrast Ring.

While the ANV-20/20 test provides a quick and easy way to check the level of contrast visible in the goggle, it may not be sensitive enough to identify lower contrast thresholds (i.e. smaller differences in contrast). An alternate test can be done by manufacturing Landolt rings of varying levels of contrast (see Figure 3-1, Figure 3-5). The Landolt rings follow a simple 1:5 ratio in that the diameter is five times the gap in the ring and five times the width of the ring. One simply needs to use different gray levels to draw the rings with different levels of contrast. The typical contrast value, also known as the Michaelson contrast ratio, is derived from the following equation:

$$\text{Contrast ratio} = \frac{L_{\max} - L_{\min}}{L_{\max} + L_{\min}}$$

Figure 3-5: Low Contrast Landolt Ring Charts.

In the case of the Landolt ring, L_{max} (maximum luminance) is the luminance of the background and L_{min} (minimum luminance) is the luminance of the ring. Measurement of the contrast needs to be done on the printed copy of the stimuli since the contrast on the monitor and the contrast on paper are invariably different. The contrast measurement can be done with a basic photometer. The contrast can be measured directly from the chart itself[5] or through the NVGs. While measuring the luminance values from the chart through the NVGs is not the ideal method photometrically, it is appropriate in two senses. First, most visible-range photometers can be fitted with a filter designed to replicate the filtering of the human eye. The photometer then "sees" the luminance in the goggles in the same way that the pilot would, which is the primary concern when performing the contrast measurement tests. Second, certain types of printers or laminate coatings that might be used on the chart can affect the contrast of the stimuli as seen through the NVGs.

3.1.6 Checks for Imaging Defects

There are a variety of imaging defects that may appear as the result of NVG malfunctions. These defects may include the following (See Appendix 1 for more detailed descriptions of these defects):

- Shading (Dark edges along perimeter of the image);
- Edge Glow (Bright area along outer edge of the image);
- Bright Spots (Constant or intermittent spots in the image);
- Flashes/Flickering;
- Honeycombing (Dark honeycomb pattern over the NVG image);
- Distortion (Straight lines appear bent);
- Veiling Glare (Bright haze or bright artefacts in the NVG image); and
- Dark Spots (Constant dark spots in the NVG).

These defects, the diagnostics for each defect and the course of action are described in detail in the Hoffman Engineering ANV-202/20 Manual (Hoffman Engineering, 1997). Most of the defects listed above may require NVG maintenance action, if the problem(s) are of sufficient magnitude. Taking dark spots as an example, the loss of 1 – 2 pixels in the goggle phosphor in the middle of the field of view may not warrant goggle maintenance while a the loss of a 5 – 6° area would likely require maintenance.

[5] The stimuli on the chart may be too small to accurately capture the luminance value. Test patches of the gray levels used for the stimuli may be required in order to conduct contrast ratio measurements.

Chapter 4 – AIRCRAFT NVG AIRWORTHINESS

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4.1 NVG AIRWORTHINESS TESTING

A guideline for NVG airworthiness testing for the Canadian forces was developed by Aeronautical Engineering and Testing Establishment (AETE) and is presented here briefly in Sections 4.1.1 to 4.1.8.2.

In order to conduct NVG operations safely, each aircraft must be suitably configured. Determining the suitability of an aircraft for NVG flight operations is a complex task involving extensive ground and flight tests. The aim is to outline the various tests that are typically conducted prior to authorizing a single aircraft or a fleet for employment in NVG flight operations. These tests will also determine the effectiveness of the airborne platform for future NVG research programs, as these tests will highlight any deficiencies in aircraft lighting or other systems (e.g. rad alt) which may limit NVG research.

The aim of initial ground testing is to provide NVIS compatibility proof of compliance recommendations based on NVIS Visual Acuity measurements. In addition, all aircraft cockpit lighting systems and sub-systems must demonstrate an acceptable level of NVG compatibility, unaided and aided night detection capability, and daytime high ambient light readability.

4.1.1 Essential Test Items

The equipment listed in this section is suggested for NVG airworthiness testing based on availability in North America. Equivalent systems may also be used where available.

- **Hoffman Engineering Model ANV-20/20**. The Hoffman 20/20 test kit is a portable reference device that facilitates accurate NVG acuity adjustments under simulated moonlight and starlight illumination levels.
- **Visual Acuity Resolution Charts**. Typically the modified USAF Tri-Bar Chart can be used to test the minimum level of detail that can be seen by the pilot. The chart was designed to be placed 20-ft from the test subject and can be used to quickly determine the NVIS visual acuity under varying lighting conditions.
- **Hoffman LM-33-80 Starlight Projector (or equivalent-see above for NVG lighting)**. A light projector used to illuminate the VA targets. This projector provides very precise control of lighting source intensity and colour spectrum.
- **Pritchard 1530-AR Spot Photometer (or equivalent)**. This instrument is used to measure the luminance level of the visual acuity board. It can be focused on a very small area thereby allowing the user to measure luminance on a specific portion of the VA target.

- **Hoffman NVG-103 Inspection Scope**. This meter is used to determine if any cockpit lighting is incompatible, as determined by MIL-L-85762A (U.S. Navy, 1993). With the cockpit lighting set to operationally representative levels, the cockpit should be scanned to determine if any lighting source is brighter than the internal reference.
- **Hoffman ANV 410-B Night Sky Night Vision Illumination Meter**. The ANV-410 measurement system is a self-contained, hand held photometer for measuring night sky illumination levels. The device provides a direct reading in milliLUX. This device is used to measure test facility and target illuminance.

4.1.2 NVG Acuity Assessments

The ground test facility must be light tight such that the illumination of the visual acuity targets can be precisely controlled. The test subjects must be familiar with the set-up and operation of the test NVG and Hoffman 20/20 test kit. Between two and six individuals should be tested to determine the system visual acuity. The acuity of the NVG should be adjusted using a calibrated Hoffman 20/20 test kit to obtain maximum visual acuity. The internal cockpit lighting should be adjusted to operationally representative intensity levels. Test subjects with NVIS flight experience must determine the intensity levels. A 50% contrast USAF 1951 Medium Contrast Resolution Resolving Power Target (USAF Tri-Bar Chart) or a modified 50% contrast NVG Resolution Chart developed for cockpit lighting evaluations by Armstrong Laboratory typically should be used to test NVG acuity. During the evaluation, the Tri-Bar Chart targets should be set up at a distance from the observer so that a resolution pattern midway between the largest and the smallest pattern is just visible in the goggles. Care should be taken to ensure that the light falling on the acuity chart (from the Hoffman LM-33-80) is at levels appropriate to starlight, moonlight and an intermediate value between moonlight and starlight.

4.1.3 Daylight Readability

Daylight readability of the instrument panel with the naked eye must be assessed as part of an NVIS compatibility evaluation. Filters intended to make cockpit lighting NVIS compatible often result in reduced display contrast and the ability of the display to attract attention during daytime. A minimum of 2 people should be used to assess daylight readability. A light tight facility is not required for the assessment, which may be performed during daytime. The evaluators should identify any deficiencies in reading the displays, or failures to identify that a display was illuminated (e.g. caution indications) with sunlight falling on the instrument panel at a variety of angles.

4.1.4 Night-Time Readability

Night-time readability of the NVG compatible instrument panel with the naked eye is a subjective determination of the legibility of the displays under night-time operational conditions. Displays also are evaluated for their ability to attract attention, and the presence of glare, shadows or reflections. As with daylight readability, a minimum of two subjects must assess night-time readability. Prior to commencing the assessment, each subject must dark adapt for a minimum of 20 minutes, then adjust the cockpit lighting to operationally representative levels. With the subject seated in the cockpit, the data gatherer should consult a data sheet and should tell the subject which panel, display, etc., to view. Subjects should make comments on readability and the cause of any deficiencies should be recorded.

4.1.5 NVIS Radiance

MIL-L-85762A specifies that NVIS radiance be measured from the cockpit displays. Maximum allowable NVIS radiance theoretically represents the amount of energy within the spectral response of the NVGs that would be reflected from a defoliated tree under starlight conditions. MIL-L-85762A establishes NVIS radiance limit values to ensure that the cockpit lighting is no brighter than the outside scene during this

operating condition. NVIS radiance limit values are specified in Table IX of MIL-L-85762A. Any lighting that produces radiance greater than the specified NVIS radiance value is incompatible by definition.

NVIS radiance can be measured using a Hoffman NVG-103 Inspection Scope. The cockpit lighting should be adjusted to an operationally representative level by a dark-adapted subject and then measured by the evaluator using the inspection scope. The inspection scope's internal reference source should be adjusted to 1.6x 10^{-10} NR_B[1] or as specified in MIL-L-85762A Table IX. The cockpit should be scanned to identify any light sources appearing brighter than the reference source. Any bright light sources should then be measured, and the results should be recorded on data sheets. **NOTE:** MIL-L-85762A specifies that a spectroradiometer be used to measure radiance, and that NVIS radiance is then computed. Because of their size, it should not be feasible to use a spectroradiometer during this evaluation. Although the NVG-103 is not as accurate as a spectroradiometer, it is specifically designed for making field measurements. NVIS radiance is usually the last assessment of the evaluation because, unlike daylight readability, night-time readability, or NVG-aided VA, the results are less likely to be affected by evaluator fatigue.

As a part of the NVIS radiance inspection, the evaluators should also examine the cockpit for the following issues:

- Light leaks;
- Luminance uniformity and balance; and
- Reflections.

4.1.6 Human Factors Analysis

Human factors associated with the internal lighting and external lighting systems and associated aircrew equipment should be evaluated concurrently with the airworthiness ground and flight tests of the NVG system. The assessment should consider the following:

- Normal Entry and Egress (Emergency egress must also be included);
- Workspace Requirements;
- Crew Station Layout;
- Internal and External Field of View; and
- Lighting Controls.

4.1.7 Flight Tests

The following sections will deal with the specific flight tests required to assess the airworthiness of the NVGs[2]. It should be noted that the flight test profiles specified in Section 4.1.7.4 cover a broad range of NVG operations. Some of these tests may not be required if they are not part of the normal operations of the flight test organisation or the end goggle users. Similarly, NVG HUD or symbology testing would not be required if the NVG system does not have or support symbology.

4.1.7.1 Objectives

The objectives of the NVG acceptance flight test are as follows:

- Perform limited qualitative assessments of the readability of the aircraft's internal lighting to include any displays during daytime flight, during unaided night-time flight and during NVG flight;

[1] Night vision radiance for class B NVG filters.

[2] Reising, Antonio and Fields (1996) also describe a series of procedures that can be used to conduct field evaluations of NVG/aircraft compatibility.

- Perform limited qualitative assessments of the impact of the aircraft's internal and external lighting on external visual references and eye strain in unaided and aided night lighting conditions;
- Perform limited qualitative assessments of an NVG HUD to include assessments of the symbology for suitability in the designated aircraft role (as required); and
- Determine the widest safety-of-flight envelope of operations for all relevant operational and training flight profiles.

4.1.7.2 NVG Acceptance Flight Test Criteria

All lighting systems must demonstrate an acceptable level of NVG compatibility, unaided/aided night detection capability, and daytime high ambient light readability. The aircraft anti-collision and position lighting systems must demonstrate an acceptable level of NVG compatibility and provide sufficient visual cueing, for safe and effective flying particularly with respect to in-flight collision avoidance during single-ship and formation operations (if applicable). The various aircraft searchlights should provide sufficient visual cueing to operate safely in all approved NVG profiles, without adversely impacting on the performance of the NVG. All testing must be performed in a variety of lighting conditions representative of day (preferably bright sunlight at a variety of sun incidence angles and overcast if available) and unaided/ aided night (preferably minimum available ambient light) lighting conditions to ensure that the widest range of mission representative conditions are considered.

The test team must qualitatively assess any reductions in visual cueing resulting from any of the internal and external lighting systems during ground tests and during the performance of various low, medium, and high gain flight tasks. Similarly, the test team must qualitatively assess the ease of detection of any of the systems and modifications (internal and external) during ground tests and during the performance of various low, medium, and high gain flight tasks. Specifically, the test team should determine if there is any increased aircrew workload or any unexpected hazard to flight resulting from reduced visual cueing caused by any of these systems.

The flight tests must be conducted in VMC conditions for daylight and night-time flight conditions to ensure safety of flight. The effectiveness of the goggles under degraded conditions could be tested at a later time, with appropriate precautions (ability to revert to instrument flight to return to base).

4.1.7.3 Flight Test Profiles

The specific mission profiles to be performed during the evaluation should be representative of the flight operations associated with the aircraft fleet under test. For a SAR aircraft, the following mission elements/ tests are suggested: forward flight, manoeuvring and continuous turns, approaches and departures, low level (200/50-ft above the highest obstacle (AHO)) and tactical (clear of obstacles or as low as can safely be achieved within the handling qualities limits of the aircraft) navigation and manoeuvring, slinging, hoisting, ship hoisting, confined areas, slope landings, circuits (500-ft (unaided), and 200/50-ft AHO (aided)), mission representative SAR search patterns, over water flight, mountain flying, non-tactical and tactical formation, and any relevant Aeronautical Design Standard (2000) helicopter manoeuvres required to baseline the aircraft's handling qualities in various visual cueing environments[3].

During all NVG testing conducted below 100-ft AHO the non-flying pilot should standby on the flight controls. This will ensure that there are essentially two pilots engaged in fully attended flight operations. All comments made by the test team should be qualitative and should be noted by a designated test team member, typically the flight test engineer (FTE), on board during testing. All test team members should qualitatively assess the following characteristics during the performance of a variety of mission representative tasks:

[3] While some elements of the SAR NVG flight test may be common to many organizations, not all of the tasks will be appropriate to every NVG operation.

- Cockpit compatibility of the lighting system under assessment in daylight and unaided/aided night lighting conditions with direct and indirect sunlight (or moonlight), as applicable;
- Ease of readability of cockpit instruments and gauges, to include all comments related to glare;
- Impact on NVG gain;
- Impact on external visual cueing, particularly with various weather radar image brightness and contrast settings, since this is expected to be one of the least compatible cockpit displays;
- Impact on field of view (FOV) and field of regard (FOR);
- Impact of any observed light leaks;
- Impact on quickly adapting from inside to outside references and vice versa;
- Impact on judging depth perception, obstacle clearances, obstacle closure rates, and aircraft height above ground/water, particularly during hovering and low level flight manoeuvres;
- Impact on reading and interpreting standard aircraft maps and approach plates;
- Impact on transitioning from visual to instrument references, and vice versa;
- Impact on overall cockpit and crew workload; and
- General confirmation of results noted during ground testing.

4.1.7.4 Specific Flight Profiles

The following sections describe some of the basic (e.g. forward flight, hover) and operationally specific (e.g. slung-load, mountain flying) flight test profiles that should be examined to determine the usability of the goggles.

4.1.7.4.1 Forward Flight

Qualitatively assess the ease of maintaining a constant targeted altitude (indicated or reference (AHO)) while performing standard pilot transit and navigation duties. During unaided night flight operations, this task should not be flown below 500-ft AGL. During aided night flight operations, this task should be flown at 200-ft AHO initially and should then be stepped down to 50-ft AHO in decrements of 50-ft. Flight below 50-ft AHO should only be performed in 5-ft decrements. IFR transit flight duties should also be performed, when simulating flight in IMC. In all cases, internal lighting must be adjusted to operationally relevant levels. The cockpit displays should be altered to include the weather radar or forward looking infrared information (if applicable), as well as the standard instrument displays in an attempt to assess all possible configurations that may be used operationally. External lighting should be assessed in Normal and NVG modes as applicable. Testing must be performed over varying terrain surfaces and contrast levels to include flat and mountainous terrain, grass, trees, and snow covered land surfaces, and water/ice. Testing must be performed throughout the aircraft's speed range, with emphasis on typical transit speeds for VFR and IFR operations. Flying at slower speeds initially and working up toward faster speeds as required will provide a build-up approach to testing. The crew should assign handling qualities ratings during performance of the task in accordance with the alternative pilot rating scale for NVG evaluations, referred to as the Pilot Rating Scale for Automatic Flight Control Systems and Visual Cueing (PRSA + V). Ratings of 7 or greater should constitute failed test criteria and should result in a cease in testing. A detailed description of this rating scale can be found in Green (1994).

4.1.7.4.2 Manoeuvring and Continuous Turns

Qualitatively assess the ease of maintaining a constant targeted angle of bank (AOB), altitude, and airspeed for both manoeuvring and continuous turns. Manoeuvring turns are considered to be turns limited to aircraft heading changes of 90° or less. Continuous turns are considered to be turns resulting in aircraft

heading changes of more than 90°. Testing must be conducted using a build up approach by starting with small AOB and increasing, typically in 5° increments, to larger AOB. During unaided night flight operations, this task should not be flown below 500-ft AGL. During aided night flight operations, this task should be flown at 200-ft AHO initially and then stepped down to 50-ft AHO in decrements of 50-ft. Testing performed below 50-ft AHO must be performed gradually and in 5-ft decrements. Internal and external lighting considerations, terrain and surface contrast considerations, and airspeed ranges, are to be tested in a similar fashion to the methods described in paragraph 4.1.7.4.1.

4.1.7.4.3 .Approaches and Departures

Qualitatively assess the ease of maintaining sight picture and closure rates during approaches, and aircraft tracking and obstacle clearance/avoidance during departures. This testing should be performed in daylight and unaided/aided night lighting conditions, during dedicated circuits to an airfield and to unlit fields, taxi manoeuvres, as well as during typical field approaches and departures throughout the evaluation. Internal and external lighting considerations, terrain and surface contrast considerations, and airspeed ranges, are to be tested in a similar fashion to the methods described in paragraph 4.1.7.4.1. Handling qualities ratings and pass/fail criteria should also be in accordance with paragraph 4.1.7.4.1.

4.1.7.4.4 Sloping Ground Operations

Qualitatively assess the ease of performing sloping ground operations. This testing should be performed during unaided and aided night lighting conditions. Internal and external lighting considerations should be tested in a similar fashion to the methods described in paragraph 4.1.7.4.1. The crew should assign handling qualities ratings during performance of the task in accordance with the Cooper-Harper Rating Scale, referred to as HQR. The technique for assigning an HQR should be in accordance with the methods described in the U.S. Naval Test Pilot School Flight Test Manual (1995). Ratings of 7 or greater should constitute a failed test criterion and should result in a cease in testing.

4.1.7.4.5 Confined Areas

Qualitatively assess the ease of maintaining sight picture and closure rates during approaches to, and aircraft tracking and obstacle clearance/avoidance during departures from, a confined area as well as to assess the ease of manoeuvring for landing within a confined area. This testing should be performed during unaided and aided night lighting conditions. A build-up will occur by performing this manoeuvre to areas with no less than 2-rotor diameters of clearance initially, then working down to some minimum amount of clearance around the aircraft, in 5-ft decrements. The minimum desired clearance must be based on operational requirements. Internal and external lighting considerations, and terrain and surface contrast considerations, should be tested in a similar fashion to the methods described in paragraph 4.1.7.4.1. Handling qualities ratings and pass/fail criteria should also be in accordance with paragraph 4.1.7.4.1.

4.1.7.4.6 Slung Load Operations

Qualitatively assess the ease of maintaining sight picture and closure rates during approaches to, and aircraft tracking and obstacle clearance/avoidance during departures from, the slung load area as well as to assess the ease of manoeuvring for pickup and drop off of the slung load. This testing should be performed during unaided and aided night lighting conditions. Testing should be limited to one load, unless it is convenient to operate with different loads. Internal and external lighting considerations, terrain and surface contrast considerations, and airspeed ranges, should be tested in a similar fashion to the methods described in paragraph 4.1.7.4.1. Maximum airspeeds, based on aircraft type and operational requirements, should be adhered to during all slinging operations. Handling qualities ratings and pass/fail criteria should also be in accordance with paragraph 4.1.7.4.1.

4.1.7.4.7 Hoisting Operations

Qualitatively assess the ease of conducting rescue hoist operations in unaided and aided night lighting conditions during over land/water operations. Hoisting should be initially assessed in a similar manner to the method used for assessing confined area operations. The aim of this testing should be to qualitatively assess the ease of maintaining sight picture and closure rates during approaches to, and aircraft tracking and obstacle clearance/avoidance during departures from, the hoist area as well as to assess the ease of conducting the actual hoist operation at a selected hoist area. Ship hoisting should be conducted to the stern and bow of large and small vessels. Testing may include the use of marker flares, in accordance with applicable SAR operations. The use of marker flares for visual reference aids may be included in this test. Internal and external lighting considerations should be tested in a similar fashion to the methods described in paragraph 4.1.7.4.1. Handling qualities ratings and pass/fail criteria should also be in accordance with paragraph 4.1.7.4.1.

4.1.7.4.8 Over-Water Operations

Qualitatively assess the ease of performing shore crawl, forward flight, manoeuvring and continuous turns, transitions, and hovers during over-water flight in unaided and aided night lighting conditions. The range of airspeeds to be tested during shore crawl sequences should include, as a minimum, typical transit speeds for VFR operations in conditions of poor visibility when preparing for alternative action. Safe distances from shore and heights should be governed by aircraft performance (e.g. single engine vs. multiple engines). For military operations, shore crawl, forward flight, and manoeuvring and continuous turns testing should not be performed below 500-ft AGL for unaided night flight operations. These sequences could be performed down to 50-ft AHO during aided military night flight operations. Internal and external lighting considerations should be tested in a similar fashion to the methods described in paragraph 4.1.7.4.1. Handling qualities ratings and pass/fail criteria should also be in accordance with paragraph 4.1.7.4.1.

4.1.7.4.9 Mountain Flying Operations

Qualitatively assess the ease of performing transit flight, approaches, and departures in mountainous terrain. Approaches and departures should be to/from approved, daytime-assessed, mountain landing pads. During mountain flying testing, at least one pilot on board should have completed formal mountain-flying training of some form. This testing may be limited to aided night lighting conditions. Internal and external lighting considerations, terrain and surface contrast considerations, and airspeed ranges, should be tested in a similar fashion to the methods described in paragraph 4.1.7.4.1. Handling qualities ratings and pass/fail criteria should also be in accordance with paragraph 4.1.7.4.1.

4.1.7.4.10 Degraded Modes

Qualitatively assess the ease of flying the aircraft in various degraded lighting and AFCS modes. Degraded lighting modes to be assessed should consist of flight with internal and/or external lighting completely blacked out, as well as with various cockpit caution and warning lights illuminated. All relevant degraded AFCS modes should also be tested. All degraded modes should be assessed in unaided/aided night lighting conditions. In all cases, handling qualities ratings and pass/fail criteria should be in accordance with paragraph 4.1.7.4.1.

4.1.7.4.11 Recirculating Phenomena

Qualitatively assess the ease of maintaining sight picture and closure rates during approaches, and aircraft tracking and obstacle clearance/avoidance during departures in recirculating phenomena such as snow, dust or sand. Testing should also be aimed at qualitatively assessing the ease of maintaining the aircraft's plan position during in-ground-effect (IGE) and out-of-ground-effect (OGE) hovers. This testing should be

performed in unaided and aided night lighting conditions. Handling qualities ratings and pass/fail criteria should be in accordance with paragraph 4.1.7.4.1. Internal and external lighting may be varied in accordance with paragraph 4.1.7.4.1. However, specific emphasis should be placed on assessing the impact of the aircraft's searchlights on external visual references. Recommendations should be provided with respect to where to situate these lights and when they should be specifically selected/de-selected.

4.1.7.4.12 Flight Envelope Definition

The entire safe flight envelope for NVG operations in the aircraft should be defined prior to airworthiness flight testing and modified as required based on test results. The following is a list of the known variables specifically relevant to NVG envelope definition testing that the researcher operator should be aware of:

- Ambient light levels;
- Aircraft internal / external lighting;
- Terrain/topography;
- Surface contrast;
- Flight task gain;
- Weather;
- Aircraft flight control system configuration (i.e. level of augmentation);
- Extent of degraded modes;
- Pilot ability and training; and
- Altitude / Airspeed / Ground speed.

Specific information regarding the NVG envelope parameters should be developed by experienced pilots and researchers based on their own operational constraints. A measured approach to defining the envelope is to start with reasonably safe conditions such as:

- A reasonably high altitude;
- Good visibility conditions (e.g. full moon, no precipitation);
- Highly trained pilots;
- Augmented flight control systems (if available);
- Non-aggressive manoeuvres;
- Compatible aircraft lighting; and
- Level terrain.

Once a reasonable level of confidence is attained in this sort of flight regime, the envelope can begin to expand, in one dimension at a time, to include more diverse flight scenarios (e.g. poorer visibility or more aggressive flight manoeuvres).

4.1.8 Heads Up Display (HUD) Symbology

The HUD display is one of the few instances where the pilot will look through the goggles to view the display. The visibility and utility of the HUD symbology must be assessed through the goggles. The following sections describe possible procedures for determining issues with latency (e.g. lags in the symbology display) and the basic elements of evaluating NVG symbology.

4.1.8.1 Latency Assessments

The emphasis of this assessment should be on display symbology used for maintaining aircraft control. This should include aircraft attitude, heading, altitude (radar and barometric), airspeed, and vertical speed. This portion of testing should also address the torque and rotor rpm displays whenever the aircraft under test possesses adverse characteristics with its torque sensing system, and if the obvious hazards associated with a low inertia rotor exist (e.g. over/underspeed, and difficulties in autorotation). The pilot and/or co-pilot should perform various flight tasks aimed at highlighting the latency of a particular display parameter (e.g. a small step input on the collective). If latency is observed to be a problem, test team personnel on board the aircraft must attempt to hand record the data provided verbally by the pilot or co-pilot. Specifically, the pilot and/or co-pilot should verbally state the NVG HUD displayed value of a given parameter over time and the data recorder should record these values and quickly record the value of the same parameter displayed on the instrument panel. The preferred method of obtaining this data should be to access it directly from a data bus recorder, but if this method is not available, the above-mentioned technique may be used.

4.1.8.2 Symbology Assessments

Symbology assessments should consist of qualitative ground and flight assessments of the suitability of each symbol in the symbology set. This task should be performed in order of priority of symbols, from a safety of flight perspective, to ensure that the most important items are addressed first. The symbols with the highest priority should include aircraft attitude, heading, altitude (radar and barometric), airspeed, and vertical speed. The torque and rotor rpm displays may also be considered as high priority items, for the same reasons mention in Section 4.1.8.1. Testing should consist of evaluating the intuitiveness, ease of interpretation, and the impact on FOV of a particular display symbol. Emphasis should also be placed on power loss or failure mode indications including warning, caution and advisory symbology, as well as display endpoints. Warning, caution, and advisory symbology assessments should include comments from the test team related to their ability to attract the pilot’s attention. Display endpoint assessments should attempt to determine if a display indicates zero or its last indicated value prior to stopping once the NVG HUD parameter display range is exceeded or if power to the HUD is lost.

4.1.9 Symbology as an Aid to NVG Systems

Symbology adds a new dimension to NVG operations providing pilots with critical information that normally would be presented heads-down. For nearly all NVG systems, the symbology presentation is accomplished via the attachment of specially designed presentation optics. While testing the symbology can be a highly complicated process worthy of lengthy discussion, the overall goal is to ensure that the information displayed is critical to the pilot and that the pilot can readily see and interpret the symbology. Only a brief overview of NVG symbology[4] testing is presented in this section.

The first step in evaluating the symbology is to determine if there are any obvious factors that may detract from the interpretation of the symbology such as the following:

- Symbols or alphanumeric characters are too big or too small;
- Symbols or characters are unclear (blurred or flicker);
- Too many symbols resulting in a cluttered visual field;
- Symbols or characters are too crowded or too far apart; and
- Display and update of the symbology is not subject to significant lags.

[4] Most aspects of NVG symbology testing discussed in this section will also apply to other types or modes of symbology presentation such as non-NVG helmet mounted displays or cockpit fixed heads-up displays.

Each of these types of deficiencies can impact the pilot's ability to use the display, by making it difficult to read, or by presenting data too late to be of use. Time lags may lead to poorly tuned control responses or require that the pilot adopt a more open-loop control strategy (i.e. make an input and wait to see what happens before making the next control input).

The next test of the symbology set would be to determine whether the presentation interferes with the pilot performance (i.e. does the pilot perform a given task better with or without the symbology). If the information is not important to the pilot on a regular basis, it should not be presented on an NVG HUD because it may get in the way (of the NVG image) or distract the pilot. In most cases where the pilot has a good NVG image, the pilot may only need a nominal symbology display. QinetiQ in the UK have developed an adjustable filter for NVGs, allowing them to regulate the quality of the NVG image by varying the amount of light coming into the goggles. By degrading the NVG imagery, the pilot needs to focus on the symbology to perform the task(s) (Thorndycraft & Craig, 2004, Thorndycraft, Jennings & Craig, 2005). Using this technology, the symbology can also be evaluated by determining how clear (e.g. bright, high contrast, noise free) the NVG image has to be in order for the pilot to achieve a given level of performance. For example, the best symbology would allow the pilot to manoeuvre the helicopter by using only the symbology without additional visual references (i.e. no NVG image). If the pilot continually increases the amount of light coming into the goggle to obtain a better NVG image and thereby improve performance, the symbology may not be very useful. If the pilot continues to achieve the desired level of performance even with degradations to the NVG imagery, the symbology has proven itself effective for the task.

While symbology sets are often tested as a whole, the manoeuvres chosen need to stimulate one or more dimensions of the symbology. For example, a hover task may not be useful in assessing airspeed symbology, but may be useful in evaluating a velocity vector and a height above ground display. Not only must the task stimulate the dimension being tested, the researcher must also determine what aspect of the task is being measured. For example, the effectiveness of the symbology could be determined by rating the cueing the symbology provides, by the precision of performance of the task, the speed with which the task can be performed or by various components of task performance (e.g. control inputs). It is difficult to determine the effectiveness of symbology based on workload measurements. If the symbology provides good cueing, the pilot's workload may increase, but if the symbology is difficult to interpret, the pilot's workload will likewise increase. The difference between these two conditions will be resolved by task performance, which should improve in the former case. However, workload (and situational awareness) should still be assessed to attempt to quantify how much the pilot is compensating for the symbology and whether the pilot is concentrating too much on a given aspect of the symbology.

The AETE test document presented at the beginning of this chapter noted that priority in the assessment be given to the symbol(s) that are used most often by the pilot or to the symbols that are the most critical for a given phase of flight. If a new symbol is being added, or an existing symbol is being modified, the new symbol will need to be assessed in the context of the whole display. Care must be taken to ensure that the new symbol does not detract from the pilot's situational awareness.

In terms of symbology evaluation methodologies, many of the tests used to evaluate symbology for helmet mounted displays can be applied to testing NVG symbology. A short list[5] of references is presented below in which parts (e.g. or whole symbology concepts were tested, using a variety of methods (see Atencio et al., 2002; Ercoline et al., 2002; Grunwald et al., 2006; Hughes et al., 2002, 2003; Self et al., 2003; Swenson et al., 1994; Szoboszlay & Moralez, 2006; Szoboszlay et al., 2004; Thorndycraft, 2006; Thorndycraft & Craig, 2004; Thorndycraft et al., 2005).

[5] This list is by no means complete.

Chapter 5 – NVG IN-FLIGHT RESEARCH

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5.1 FLIGHT TESTING NIGHT VISION GOGGLES

The following section presents experimental flight test methods and approaches for evaluating NVGs. In the previous section, the techniques were geared toward assessing the impact of the goggles on operational flight tasks to determine if there are restrictions or limitations on how/when the goggles are used in flight. Typically, the tests outlined in the previous section would be done to determine the acceptability of the NVGs and the aircraft for conducting future NVG operations or research. In contrast, the current section presents methods which can allow the researcher to compare in detail goggle effectiveness, compare between different goggle systems, examine effects of different types of aircraft, cultural or environmental lighting, and different weather effects, for example. The following sections describe pilot/subject selection, the different categories of NVG flight testing that might occur, objective and subjective performance measurements and some of the considerations in using each type of measurement.

5.1.1 Pilot Selection

The current section examines the basic issues associated with identifying the pilot population for the NVG research to be conducted. It is important to select pilots that are representative of the final user population of the NVG or the symbology. For example, when examining the ease of use of symbology, the researcher must consider both the pilot who has hundreds of hours of NVG flying and the pilot who has only just qualified on NVG flying. Pilot currency should also be considered in the selection of research subjects to ensure that the pilots have flown NVGs recently, or can be given additional practice flying with the goggles in the case of a non-current pilot. While qualified test pilots often provide invaluable feedback on the aspects of the system being tested, they will invariably compensate for the deficiencies in the system in ways that might be difficult for non-test pilots to match. If the time and resources are available one may wish to test both an expert and a group representative of the final users. From the test pilots, one may gain a better sense of the underlying system problems, while the end users will provide a sense of potential training issues and issues that may arise only in the operational environment.

5.1.2 Basic Categories of Flight Testing

The following sections detail the different broad categories of research flight testing including operational flight tests, developmental flight tests and certification flight tests.

5.1.2.1 Evaluating the Operational Context

As flight tests are designed, it is important to approach the flight test with a considered understanding of the operational environment. By utilizing representative pilot input as above, evaluators will be able to examine NVGs from an operational context rather than a strict “bench” science approach. This will be useful in understanding system usability in real missions. For example, NVG performance will change as function of operational context (e.g. urban to non-urban lighting conditions, changes in terrain, etc.). Flight test scientists and evaluation pilots will need to consider the impact of a dynamic flight environment on NVG function when assessing new and mature technologies in various flight test environments.

For example, in keeping with laboratory methods as described above, flight tests will need to vary environmental context (e.g. lighting, terrain features, weather) to ensure that testing is representative of operational requirements. In addition, when testing specific NVG capabilities, flight tests should consider the Concept of Operations (CONOPs) in developing studies. It is important to note that any methodological approach will have to mesh applied operational science with theoretical approaches towards studying the visual system in order to establish a full understanding of how NVGs influence pilot vision and flight performance. Finally the authors would like to stress that all NVG test scientists should be well versed with operational implementation of NVGs and should be participating in flight tests and flying operations on various airborne platforms where possible.

The approach toward operational flight testing is typically quasi-experimental utilizing domain expertise from flight test scientists and evaluation pilots as described above. Evaluation of NVGs involves incorporation of laboratory and flight test engineering evaluations (e.g. see summary in Chapter 4). Once data is available from these well controlled environments it will be necessary to flight test NVGs in a real operational environment (Rash et al. 1996; 2000). For example, NRC recently conducted an operational evaluation for the Ontario Ministry of Natural Resources to examine goggle performance in highly incompatible lighting conditions (Jennings et al., 2006). OMNR wanted to examine the feasibility of conducting operations around forest fires at night to perform personnel extractions and scan for hot spots. These are not typical applications for NVG systems and so NRC conducted a preliminary examination of the viability of these operations. The preliminary flight test involved flying around/near controlled burns, ranging in size from $1m^2$ to $5m^2$. Based on the preliminary flight test, an initial set of strategies for flying around the fire were developed and disclosed to OMNR along with a recommendation for additional phased testing around actual forest fires to fine tune the strategies.

5.1.2.2 Development Tests

As suggested by the name, development tests examine new equipment, new concepts of operation for the equipment, or new symbology. Typically the research will compare the new system or concept against the current standard to determine if the new concept is worth pursuing. Specifically, does the new system increase the safety or the capability of the NVG operation(s) enough to warrant the cost involved in changing the system. For example, one may be tasked to compare a new version of image intensifiers to determine if it is worth upgrading to the new tubes. A small increase in the dynamic range or acuity of the goggles may not be worth the increased cost of the new tubes. Significant increases in the field of view (without resolution or acuity loss), visual acuity through the goggles, or performance under a wide range of illumination conditions may increase capability sufficiently to warrant adopting new goggle technology. Significant decreases in the weight of the tubes or optics without appreciable degradations to goggle performance may also merit replacing the NVGs.

Simple subjective evaluation flights may be adequate to address the question of improvements in goggle performance, particularly when there are obvious performance differences between the old and new technologies. However, conducting tests under a wide variety of illumination/weather conditions may not be feasible if there are time constraints involved. In such cases, laboratory or simulation evaluations may compliment the flight test(s). In some cases, the performance difference(s) between old and new goggles or symbology sets needs to be quantified. When this is the case, a structured series of laboratory and flight tests will be needed, using the flight tests suggested by AETE (see summary in Chapter 4). The operational requirements of the organization may serve to expand or narrow the range of tests performed. Similarly, an initial series of laboratory tests may be useful in pointing to aspects of the system that need to be examined further in flight. Likewise, the flight test may reveal aspects of the goggles or the symbology that need to be addressed in further detail in the lab (where the tests can be performed at lower cost and lower risk).

As an example of a developmental flight test assessment of symbology for NVGs, QinetiQ and NRC conducted flight tests of new NVG symbology in 2002 – 2005 (Craig, Jennings & Thorndycraft, 2003;

Craig & Thorndycraft, 2004; Jennings, Craig, Carignan, Ellis & Thorndycraft, 2005; Thorndycraft, Jennings & Craig, 2005). In each of these flight tests, the manoeuvres selected for the symbology evaluation were suited to the maturity of the symbology being tested. In the earlier tests, the symbology was being tested to determine how it would function on the aircraft, which called for concise and controlled flight test tasks such as is the case with racetrack and the ADS-33 manoeuvres (Craig et al., 1993). The racetrack manoeuvre consisted of a number of elements (lateral hover taxi, hovering, bob-up, etc.) which the pilot performed serially. The overall score for the racetrack was determined by the speed and accuracy of the pilot's performance of the manoeuvre. As the design of the symbology and the underlying aircraft data systems improved, the percentage of ADS-33 tasks decreased and flight tasks representative of operational missions played a larger part in the evaluation (Thorndycraft et al., 2005). This incremental approach is an important aspect to developing any new system for flight test. Generally developmental tests would start with basic elements of the final mission(s) to determine the basic usability of the system. As the system improves, the complexity of the flight tasks can increase to represent more realistic or operational flight tasks.

Another reason for the gradual (staged) approach to the tests is one of safety. Many of the more recent flight tests (Thorndycraft et al., 2005) involved low-level navigation and world referenced symbology. As such, the safety pilot flew in daylight VMC, while the evaluator flew the NVG system with neutral density filters and a mask to simulate night flight. This allowed for an increased safety margin compared to having both the safety pilot and the evaluation pilot under goggles. The testing arrangement also allows the safety pilot to act as an additional observer and to note performance deficiencies that might not be visible under goggles.

5.1.2.3 Qualification and Certification

Qualification and certification testing examines the functioning of the NVG system to ensure that the goggle is working in the correct manner. The most basic of these tests is done during the standard pre-flight checks and during routine goggle maintenance checks, as described in Chapter 2. These are the basic tests performed on goggles that are already in service. Even for new equipment, the basic tests of interest (e.g. checking on goggle resolution and gain) can be done with basic test equipment such as the Hoffman ANV-126. The performance of the goggles with respect to incompatible lights and halo can easily be examined in the lab. A variety of light sources (compatible and incompatible) can be examined with the goggles to determine the relative size and intensities of the halo in response to the different lights.

5.1.3 Objective Flight Test Measures

The following sections will examine the different categories of objective measurements that can be used to assess performance of the pilot with the goggles. There are three basic ways to quantitatively measure performance of a flight test manoeuvre:

- Precision
  - Measuring RMS error in position, height, attitude, rates, etc.
  - Measuring frequency and or magnitude of the exceedance of tolerances.
  - Measuring accuracy of response to a secondary task.
- Speed
  - Time to react to a new stimulus or situation; reflects on the interpretability of the information (NVG image or symbology).
  - Time to complete as a measure of the level aggressiveness that can be attained with the system.
  - Measuring time to respond to a secondary task.

- Control inputs
  - Measuring the number of control reversals.
  - Measuring the magnitude of the control movements.
  - Frequency content of the movements.
  - Movement rates.

There are pros and cons associated with each of these kinds of measurements. The first issue is that the methods noted above measure the performance of the whole system. There must be a thorough examination of the methodology and the actual test conditions to ensure that any differences that arise are due to the experimental manipulation.

The next issue is that the goggles will affect the pilot's visual cues and so the performance will typically be denoted in terms of precision and aggressiveness. Indeed, both the precision and the aggressiveness need to be quantified as different pilots will employ a different mixture of aggression versus precision in completing the task. This source of statistical variation can be minimized by instructing the pilots to perform the manoeuvre as precisely or as aggressively as possible. While this approach represents a departure from the traditional ADS-33 methodology such that handling qualities ratings are no longer appropriate, it does make statistical analysis more viable. Alternatively, a composite score can be developed to take both the speed and precision of task performance into account. The "racetrack" manoeuvre developed by QinetiQ encouraged pilots to perform the manoeuvre quickly, but added time penalties for losses in precision so that the time to complete the course was representative of both the level of aggressiveness and the level of precision that was achieved (Thorndycraft, 2002).

One difficulty with measuring performance objectively is to find a measurement that captures performance differences that arise from the NVG test conditions. This is particularly true when developing new manoeuvres for testing. With the ADS-33 manoeuvres (see Section 5.1.4.2) there are predetermined performance criteria which can be examined objectively, in concert with handling qualities ratings (Aeronautical Design Standard, 2000). For example, with the ADS-33 precision hover task, one can measure the position error to determine and if there are any biases in position in each axis. Similarly, for the side-step and the acceleration-deceleration manoeuvres, one can measure the aggressiveness of the manoeuvre via the attitudes (roll and pitch, respectively). For the pirouette the aggressiveness can be measured via the time to complete the manoeuvre. In each of these tasks, the performance will be affected by the quality of the information provided by the NVG imagery or symbology. For example, if goggle A has a higher resolution and higher contrast image than goggle B, the increased cuing available in goggle A should allow the pilot to perform the task more precisely/aggressively.

5.1.4 Subjective Flight Test Measures

Traditionally, many of the methods for evaluating aircraft or aircraft systems were based on the pilot's subjective rating of the system. These evaluations ranged from basic verbal protocols to structured questionnaires used to derive a handling qualities rating of the pilot/aircraft system. The following sections deal primarily with the standardized handling qualities evaluation procedures, including a discussion of the ADS-33 usable cue environment (UCE) and visual cue ratings (VCR), as well as some traditional flight test workload assessment techniques.

5.1.4.1 Handling Quality Evaluation

Cooper and Harper (1969) defined flying qualities as "Those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role." A great number of engineers have occupied themselves with answering the questions of what makes good flying qualities and how to rigorously assess them (see also Harper and Cooper, 1986).

The engineers have developed a thorough methodology, discussed in Hodgkinson (1998) and Padfield (1995). In these texts it is quite clear that in the evaluation of flying qualities, engineers do not restrict themselves to looking at the aerodynamics of an aircraft. Instead, they have a more inclusive view that includes characteristics of the pilot, the aircraft, the displays, the controls and the intended mission (or task) in their investigations. The pilot is one of the key elements in the aircraft control loop and in fact, basic texts on flight tests stress that “the pilot is part of a system that is intended to accomplish a mission” (Hodgkinson 1998).

Within the flying qualities field, researchers have recognized for a long time that the visual environment influences handling qualities. Handling qualities researchers have attempted to develop methods to quantify the visual environment through the use of a usable cue environment (UCE) methodology. This methodology has not been rigorously evaluated, but it has found useful application in the assessment of the interaction between control system augmentation and the visual environment. In ADS-33 it is used to define levels of control augmentation to compensate for degraded visual cueing. This approach suggests that the pilot’s visual environment can influence his control strategy. It also highlights the fact that night vision devices, cockpit displays and lighting form a key part of the pilot’s visual environment and factors such as display sensitivity, display dynamics and display time delay affect control. There is also a realization that the external visual environment affects control. Changes to the visual environment may alter the presence of visual cues used by the pilot.

“The same aircraft might have perfectly good handling qualities for nap-of-the-earth operations in the day environment, but degrade severely at night; obviously the visual cues available to the pilot play a fundamental role in the perception of flying qualities…. e.g. the quality of the vision aids, and what the symbology should do, becomes part of the same flying qualities problem as what goes into the control system.” (Padfield, 1995).

There are many complex interactions between the visual environment, the visual aid (i.e. the NVGs), the task, the pilot, the control system and the aircraft. This combination is complex, non-linear and intricate making it inherently difficult to analyze. Effective analysis of any display must include more than modelling, simulation and laboratory tests. Pilot-in-the-loop testing is essential to uncover the full nature of the complex interactions among the pilot, aircraft, control and display systems.

There are often cases where different test conditions result in the same Handling Qualities Rating (HQR). HQR is not meant as a stand alone and requires description of why the score was given. Also cases occur where the pilot is aware of differences in workload, but the differences are not sufficiently large to warrant a different HQR. While this is a deficiency in the Cooper-Harper ratings scale, the scale was not intended to resolve fine differences in visual cueing systems such as NVGs.

5.1.4.2 ADS-33 Manoeuvres

In order to evaluate goggles or other NVG systems using ADS-33 one needs to ensure that everything except the experimental conditions are held relatively constant. The ADS-33 methodology tests the whole system and, as such, any factor that could affect performance is incorporated into the HQR. While the aircraft performance remains essentially constant, a significant amount of test time may be spent awaiting consistent environmental conditions (e.g. low winds, similar weather/lighting conditions). However, having consistent environmental conditions is necessary to isolate the effects of the test conditions (the goggles or the symbology) so that one can see only the effect of the goggles on the whole pilot-in-the-loop system.

There is a set repertoire of manoeuvres to choose from and thus care must be taken to choose a manoeuvre that may highlight the differences between the conditions under test. For example, to examine different field-of view characteristics (e.g. normal NVG field of view vs. panoramic NVGs), a manoeuvre like the

ADS-33 pirouette is a good candidate because it requires the pilot to frequently scan between the center marker and the longitudinal axis performance markers. In examining field of view, performance differences will be more likely to occur if the pilot has to make large and frequent head movements with the smaller field of view compared to the larger field of view. The ADS-33 precision hover is also a useful task in this regard, as the pilot's ability to detect drift off of the optical axis is impaired by smaller fields of view. The pilots will typically report failures or difficulties to achieve desired performance in the longitudinal axis of the hover task with small fields of view. Similarly, objective performance measures would tend to show larger RMS errors in the longitudinal position when the pilots perform the precision hover task with a small field of view.

5.1.4.3 ADS-33 Usable Cue Environment for Evaluating Pilot Visual Systems[1]

To document improvements in the visual display that the pilot uses to control the aircraft, a controlled and measured methodology is required. If this methodology is standardized throughout the research community, then the experimental results can be shared. The usefulness of this data set is enhanced if the experiment approaches the operational context in terms of task difficulty, cueing environment and flight duration. Notwithstanding this, external factors such as stress, adverse weather and ancillary tasks are sometimes difficult to control and simulate and often must be accounted for during the operational trials.

This use of flight test manoeuvres for handling qualities evaluations works well when evaluating cross-coupling, power margins or response types; unfortunately, the evaluation of a helmet mounted display also adds to the mixture the requirement to determine the visual cue environment of the pilot. The following factors as addressed above have a bearing on the pilot's ability to conduct the task:

- The amount of texture and contrast;
- The colour content;
- The value of the visual acuity;
- The size of the field of view;
- Field of regard;
- Binocular overlap;
- The presence and type of symbology;
- The image time lag;
- The quality of the image fusion; and
- The weather and lighting conditions.

All these factors are grouped together in what is termed Useable Cueing Environment (UCE). The UCE is evaluated by providing Visual Cue Ratings (VCR) during specific manoeuvres and focuses on the pilot's ability to perceive horizontal and vertical translation and attitude cues. According to ADS-33, low ratings (1-2) mean that the pilot can make aggressive/precise corrections with confidence and precision. The UCE boundary was defined using an aircraft that met the ADS 33 rate response type requirements and received a level 1 mean pilot rating during the hover, landing, pirouette, sidestep, acceleration-deceleration and bob up flight test manoeuvres. Using goggles, the field of view and opacity was varied until the pilot could no longer achieve level 1 ratings during the manoeuvres detailed above. Level 2 and 3 ratings were used to determine the UCE 2 and 3 areas respectively.

One must however remember that the main use of the UCE is as a guideline to aircraft manufacturers to determine the response type needed to complete the chosen mission task elements, given a chosen visual

[1] The following discussion of UCE is taken from Gubbels et al. (2002) and used with permission of the authors.

display (be it head-down displays, head up displays, goggles, or helmet mounted displays). In other words a scout helicopter required to conduct near earth night missions using NVG without symbology (i.e. most likely in UCE 2 conditions) would require an attitude command/attitude hold plus a rate command/ direction hold control system (Aeronautical Design Standard, 2000).

There are several limitations to the current VCR/UCE methodology for evaluating upgrades to a helmet mounted display. The first of these limitations deals with the usefulness of the UCE methodology as an engineering tool while the last two of these limitations deal with the usefulness of the results as applied to an operational application. Firstly, the use of a three-point scale with very few descriptors leads to poor repeatability. Secondly, since the cueing environment is the critical factor in the evaluation of an NVG, the external cueing must be carefully chosen. The use of cones to define manoeuvres may lead to false results if they are automatically applied to the operational context where such well-defined cues are lacking. Thirdly, the variation in aircraft flight characteristics adds to the scatter when comparing fielded equipment on different aircraft. Similarly, results obtained using rate response controls will be different from results obtained using the all-up systems of the aircraft (such as attitude command).

5.1.4.4 The UCE Rating Scale is a 3-Point Subjective Scale

UCEs are evaluated by having the pilot, given a specific set of equipment, fly specific manoeuvres to Degraded Visual Environment (DVE) criteria and provide a visual cue rating. Unlike the HQR scale, the VCR does not have a decision tree to help the evaluator. Though the scale has 5 ratings, it only provides descriptors for 3. The descriptors that are given are fairly vague and subject to wide interpretation. Compounded by the fact that the test pilot community as a whole has limited experience with these scales, the repeatability of test conditions and results is poor. The three descriptions, for ratings of one, three and five, respectively, are detailed below (note: X refers to attitude, horizontal translation rate or vertical translation rate cues):

- Good X Cues: Can make aggressive and precise X corrections with confidence and precision is good.
- Fair X Cues: Can make limited X corrections with confidence and precision is only fair.
- Poor X Cues: Only small and gentle corrections in X are possible, and consistent precision is not attainable.

These ratings are given for attitude, horizontal translation rate and vertical translation rate cues and are then plotted on Figure 5-1 to determine the UCE. Note that the poorer of the horizontal or vertical translation rates is used for the vertical axis and that heading is implied in the attitude rating.

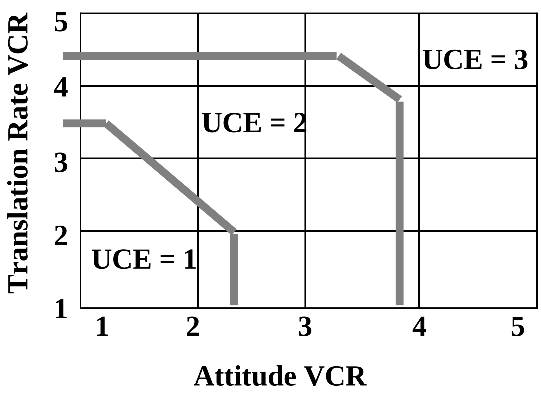

Figure 5-1: UCE Determination.

To be used as an engineering tool the VCR scale will have to be enhanced. A brief description of the factors influencing the perception of cues should be provided as background reading. This should also include which elements are to be considered when making the evaluation, including looking at issues involving the standard aircraft instruments, additional symbology and field of regard in addition to evaluating the goggles. To increase repeatability, the VCR scale will also have to incorporate better word descriptors for all five ratings. The possibility of developing a decision tree, similar in concept to the Cooper Harper rating scale, should be investigated. Questions such as ability to perceive a given amount of deviation (in terms of distance and/or rate) as well as percentage of control input and speed of input could be used to help the pilot derive a meaningful VCR. However, as the rating gets more detailed the time to go through the process will also increase and in the end, a compromise between the time to give the VCRs and the repeatability of the results will have to be made. The other option is to move away from the traditional visual cue ratings and develop a new and/or more simplified scale.

5.1.4.5 Use of Cones in the Evaluation

ADS-33 flight test manoeuvres require the use of cones/lines to define adequate and desired criteria. The unfortunate consequence of this is that the pilot, using an NVG, now has far superior point style cues than his operational community counter-part. For instance during an unmask-mask manoeuvre the pilot will perform a vertical climb and descent generally in reference to a series of nearby trees (at least one in the forward field of view to achieve lateral positioning and one to the side to achieve fore and aft positioning). These sometimes blend in with the other trees and in some cueing environments the pilot has great difficulty in detecting even moderate drift rates. On the other hand, even with frequent head movements the pilot can generally determine his position with respect to a line of cones, quickly estimate the relative position and input the corrective action. It is not suggested that the use of cones for flight-test manoeuvres be eliminated; however care must be taken in interpreting the results from an ADS-33 test environment with respect to operational flight conditions. Therefore any full-scale evaluation of an NVG must incorporate both ADS-33 flight test manoeuvres and operational type manoeuvres. To enhance comparison of results between different test agencies, a series of operational type manoeuvres should be defined that do not rely on cues such as cones.

5.1.4.6 Requirement for a Level 1 ADS 33 Rate Response Type

The VCR and UCE are based on the evaluations being conducted using an aircraft that has met the ADS 33 rate response type requirements and received a level 1 mean pilot handling qualities rating during a specified set of flight test manoeuvres. As defined in ADS-33, a level 1 aircraft must meet all of the standards for that level, which are intended to ensure that handling qualities do not a limitation on the capacity to perform the intended missions. There can be a multitude of criteria required to achieve level 1 for the various roles/missions for which the aircraft is intended. However, even if the aircraft meets level 1 for the tests performed, it could fail to meet level 1 handling qualities on dimensions/tasks that were not tested. Few aircraft meet the all of the specifications for level 1 and not all aircraft have rate-damped systems. Results obtained with a sub-level 1 (i.e. level 2 or greater) aircraft may lead to the wrong conclusions in determining the response type required for a given Mission Task Element (ADS-33). For instance, a bordering UCE 2 rating given using a sub-level 1 aircraft may in fact be UCE 1. For this reason (and others such as field of regard and cockpit instrument layout), results obtained on a specific aircraft type may not be transferable to others.

5.1.4.7 Selection of Response Type for Evaluation

The investigation or development of the fielded system might be aimed at an aircraft with much higher levels of augmentation such as translational velocity command. In this case what is the transferability of results obtained using Rate Command? The evaluation of an NVG using the VCRs and a rate-damped aircraft is more of an exercise used to benchmark the system and determine the response type required.

Past research has shown that system development performed with a rate-damped system helps define the improvements required by magnifying the deficiencies. In other words, if you evaluate a particular NVG system, each small incremental improvement will show up as a larger variation in handling quality ratings if Rate Command is used as the basis of evaluation in lieu of Attitude Command. However, along the same lines as the requirement to test the NVG in an operational context to remove the influence of the increased point cueing provided by the cones, the final system handling quality assessments of the fielded equipment should be evaluated using the intended aircraft control systems.

5.1.4.8 Workload or Pilot Compensation

In the planning stages of a goggle evaluation, the concept of pilot workload is often raised as a means of evaluating the goggles. For example, does the pilot’s workload increase when using goggle A vs. goggle B? While the concept is intuitively compelling, in practice measuring workload has proven to be a complicated proposition. Workload is a multidimensional representation of the information (sensory/perceptual) available to the pilot, the amount of processing (cognitive activity) required to make sense of the information and whatever output is required of the pilot (motor or control activity). The tools available to measure this process range from simple subjective rating scales (e.g. rate your workload from 1 – 10) to more complicated subjective rating scales (e.g. NASA TLX Hart & Staveland, 1988, Modified Cooper-Harper Workload Scale Wierville & Casali, 1983) to objective measures of pilot activity (DIMSS, physiological measures as above). For small subject samples, none of the measures works particularly well due to the variability of interpretations between subjects. For example, the modified Cooper-Harper workload scale often is treated as a simple 10-point workload rating, while other evaluators use the decision tree to arrive at a workload rating. The variability associated with the set of subjective questionnaires might be alleviated to a certain extent by pre-training. Pre-training may diminish inter-subject variability enough to allow workload ratings to distinguish between the workload associated with using the different goggles (or symbology sets). However, typically the subjective rating scales either cannot resolve differences in workload between test conditions or can only resolve obvious differences in workload.

Similarly, standard handling qualities evaluations can be used to determine the level of pilot compensation required to attain a given level of performance. Within each level of performance (desired, adequate and sub adequate) the pilot may need to employ different levels of compensation or strategies to deal with the limitations of the system. As indicated in Section 5.1.4.2, when all other aspects of the system (helicopter, weather, winds, lighting) are consistent, the remainder of the pilot compensation should be due to the test conditions. In general terms, the level of pilot compensation can be regarded as an element of the pilot’s workload.

Chapter 6 – SUMMARY

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This document has provided a broad overview of the general methodological approaches used in the test and evaluation of NVGs. Specifically, the authors advocate a comprehensive approach in which flight and laboratory tests are used to assess NVG function in real operational contexts. This approach will involve using a repertoire of specific assessment methodologies. This document should be considered as best practices when approaching test and evaluation of NVGs. As the overall theme of this document, the authors would stress that evaluators:

1) Are fully versed and knowledgeable of NVG function, handling and utilization;
2) Possess a working knowledge of laboratory and flight test methods; and
3) Anchor all evaluations in a well defined operation context.

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Appendix 1 – EXPANDED INFORMATION

These definitions are based on MAWTS-1 (1998) and Jones and Shwalier (1998).

ABSORBANCE – The ratio of the radiant energy absorbed by a body to that incident upon it.

ACUITY – The human eye has a nominal resolution of 1 minute of arc. The common measure of visual acuity is based on reading letters with 1 minute line width, Snellen letters, or patterns with similar detail, such as Landolt rings. Visual acuity is reported as a fraction. The denominator is the test distance (usually 20 feet). The numerator is the relative size of line that can be resolved. That is, 20/40 indicates that the resolution was 2 minutes of arc, twice the nominal value. In other words, that individual can resolve at 20 feet what a "normal" person can at 40 feet.

AIDED – A term used to describe those times when NVGs are being used as an aid to night vision.

ALBEDO – The ratio of the amount of light reflected from a surface to the amount of incident light.

ASTRONOMICAL TWILIGHT – The period of time, beginning in the morning and ending in the evening, when the center of the sun is 18 degrees below the horizon. After astronomical twilight in the evening, the sun does not contribute to sky illumination.

AUTOMATIC BRIGHTNESS CONTROL (ABC) – One of the automatic gain control circuits found in second and third generation NVG devices, this feature automatically reduces voltage to the microchannel plate to keep the image intensifier's brightness within optimal limits and protects the tube. The effect of this can be seen when rapidly changing from a low light to high light conditions. The image gets brighter and then, after a momentary delay, dims to a constant level.

AUTOMATIC GAIN CONTROL (AGC) – Comprised of the automatic brightness control and bright source protection circuits. Is designed to maintain image brightness and protect the user and the image tube from excessive light levels. This is accomplished by controlling the gain of the intensifier tube.

BLACK SPOTS – These are either cosmetic blemishes in the image intensifier or dirt or debris between the lenses. Black spots that are in the image intensifier tube do not affect the performance or reliability of the night vision device and a number of varying sized spots are inherent in the manufacturing process. Spots due to dirt or debris between the lenses should be removed by careful cleaning if the system is designed for interchangeable optics.

BLACKBODY – An ideal surface that completely absorbs all radiant energy falling upon with no reflection.

BLOOMING – Common term used to denote the "washing out" of all or part of the NVG image due to de-gaining of the image intensifier tube when a bright light source is in or near the NVG field of view.

BRIGHT SOURCE PROTECTION (BSP) – An electronic function that reduces the voltage to the photocathode when the night vision device is exposed to bright light sources such as room lights or car lights. BSP protects the image tube from damage and enhances its life. However, BSP may have the effect of lowering resolution when it is functioning.

BRIGHT SPOTS – These are signal- induced blemishes in the image area caused by a flaw in the film on the MCP. A bright spot is small, non-uniform, bright area that may flicker or appear constant.

Bright spots usually go away when the light is blocked out. Not all bright spots make the ANVIS unserviceable. A test can be performed as follows: Place a cupped hand over the lens to block out all light. Make sure any bright spot is not simply a bright area in the viewed scene. If the bright spot remains, an emission point exists and needs to be checked.

BRIGHTNESS GAIN – When referring to an image intensification tube, brightness gain is the ratio of the brightness of the output in units of foot-Lambert, compared to the illumination of the input in foot-candles. A typical value for a GEN III tube is 25,000 to 30,000 Fl/fc. A tube gain of 30,000 Fl/fc provides an approximate system gain of 3,000. This means that the intensified NVG image is 3,000 times brighter to the aided eye than to the unaided eye.

BROWNOUT – Condition created by blowing sand, dust, etc., which can cause the pilots to lose sight of the ground. This is most commonly associated with landings in the desert or in dusty landing zones.

CHICKEN WIRE – An irregular pattern of dark lines in the Field-of-View (FOV) throughout the image area or in parts of the image area. Under the worse condition, these lines will form hexagonal or square-wave shaped lines.

CIVIL NAUTICAL TWILIGHT – The period of time, beginning in the morning and ending in the evening, when the center of the sun is 6 degrees below the horizon. Illuminance level is approximately 3.40 lux and is above the usable level for NVG operations.

COLLIMATION – The act of making rays of light travel in parallel lines. Also the process of aligning the various internal optical axes of a system with each other.

CONVERGENCE – The shifting of an observer’s eyes inward to view a nearby object, i.e. crossing the eyes.

COUNTERWEIGHT SYSTEM – Counterweight systems are used to adjust the center of gravity of the pilot’s flight helmet with goggles installed. Without counterweights, there can be a fatiguing forward and downward force on the pilot’s neck. The counterweight system may consist of a weight bag and counterweights. The Army’s recommended initial weight is 12 ounces for one of its systems. Pilots are instructed to add or remove weight to achieve the best balance and comfort, not to exceed 22 ounces. Attachment of the weight bag is below the back of the helmet with the battery pack mounted vertically above it. The adjustment of the weight is to be made with the binoculars attached and flipped down.

CYCLES PER MILLIRADIAN (CY/MR) – Units used to measure resolution. A milliradian is the angle created by one yard at a distance of 1,000 yards. This means that a device that can detect two 1/2 yard objects separated by 1/2 yard at 1,000 yards has a resolution of 1.0 cy/mr.

DEGRADED VISUAL ENVIRONMENT (DVE) – Generally DVE conditions refer to any phenomenon which reduces the pilot’s vision. Under the traditional definition, NVGs qualify as a degraded visual environment largely due to the goggle’s reduced field of view. In terms of a degraded NVG visual environment, it would consist of night conditions during which the pilot has difficulty using the NVGs. Scintillation or visual obscurations that are (or forecast to be) present pose extra pilot workload. Pilots should always be cognizant of the dangers associated with these types of conditions. For example: a new moon combined with overcast skies and very little cultural or reflected lighting.

DIOPTER – A measure of the refractive (light bending) power of a lens. The unit of measure used to define eye correction or the refractive power of a lens. Usually adjustment to an optical eyepiece accommodates for differences in individual eyesight. Many military systems provide +2 / -6 diopter range.

DIVERGENCE – The shifting of an observer's eyes vertically, one up and one down.

DISPLACED GOGGLES – Displaced goggles have the eye pieces displaced from the user's eyes such that the user can look through the goggles for night vision aiding or can look under, above, or to the sides of the goggles with unaided vision. A pilot wearing this type of goggle will focus the goggles for far vision, which is required for out of the cockpit viewing. The displaced design has the advantage of allowing pilots to look down under their goggles at the instrument panel or up at their overhead panel without having to first refocus the goggles for near distance. The side viewing allows pilots' peripheral vision to pick up some peripheral visual cues without having to turn the head.

DISTORTION – In an optical system, alterations in the shape of the displayed image as compared to the actual image. Geometric distortion is inherent in all GEN 1 and some GEN II image intensifiers that use electrostatic rather than fibre optic inversion for image inversion.

DIVERGENCE – The shifting of an observer's eyes outward.

EDGE GLOW – A bright area (sometimes sparkling) in the outer portion of the viewing area. Edge glow is sometimes caused by an emission point (or series of emission points) just outside the field of view, or by a defective phosphor screen that permits light feedback to the photo-cathode. To check for edge glow, block out all light by cupping a hand over the lens. If the image monocular assembly is displaying edge glow, the bright area will still show up.

ELECTROLUMINESCENT (EL) – Referring to light emission that occurs from application of an alternating current to a layer of phosphor.

ELECTRO-OPTICS (EO) – The term used to describe the interaction between optics and electronics, leading to transformation of electrical energy into light or vice versa.

EXIT PUPIL – In an optical system, the rays of light passing through the system will be limited by either the edges of one of the components such as the eyepiece lens, or by an internal aperture. The image passing through the entrance side of the optical system is the entrance pupil. The image passing out the exit side is the exit pupil. This image forms a small disk containing all of the light collected by the optics from the entire field-of-view.

EYE RELIEF – The distance the eyes must be from the last element of an eyepiece in order to achieve the optimal image.

EYEPIECE LENS – The eyepiece lens focuses the image from the fiber optic inverter on to the eye by adjusting for individual eye acuity. There are two eyepiece lens assemblies in current systems; the 15 mm and the 25 mm eyepiece lens assembly. Tests show the larger eyepiece is more effective. This lens assembly is designed to provide some adjustment for the user to compensate for minor vision deficiencies (i.e. diopter adjustment). However, the assembly does not correct for all eye deficiencies and does not replace the need for wearing prescribed spectacles or contact lenses.

FIBRE OPTIC INVERTER – A bundle of microscopic light transmitting fibers twisted 180 degrees.

FIELD OF VIEW (FOV) – The width or spatial angle of the outside scene that can be viewed through the intensifier tubes measured laterally and vertically. Typical NVGs have a 40° FOV.

FIXED PATTERN NOISE – Also referred to as Honeycomb. This is usually a cosmetic blemish characterized by a faint hexagonal pattern throughout the viewing area that most often occurs at high-light

levels or when viewing very bright lights. The pattern can be seen in every image intensifier if the light level is high enough.

FLASHING, FLICKERING OR INTERMITTENT OPERATION – The image may appear to flicker or flash. This can occur in either one or both monocular tubes. If there is more that one flicker, check for loose wires, loose battery cap, or weak batteries.

FOOT-CANDLE – A measure of luminance; specifically, the luminance of a surface upon which one lumen is falling per square foot.

FOOT-LAMBERT – A measure of luminance; specifically the luminance of a surface that is receiving an illuminance of one foot-candle.

FULL FACE GOGGLES – Full face goggles are an earlier goggle form factor. The goggle covers the entire upper face much like swimming goggles or masks. A pilot wearing this type of goggle cannot look under, over, or to the side of the goggles, but must instead move his head up, down, or sideways to see the overhead panel, instrument panel, or objects in peripheral vision, respectively. This creates certain human factors problems for pilots. It is too time-consuming to continually refocus the goggles between far and near viewing. So, pilots have to focus one lens to far distance and the other to near distance and then use only the appropriate eye for viewing outside the cockpit or inside the cockpit, respectively. Full face goggles are not acceptable for civil aviation use.

GAIN – When referring to an image intensification tube, the ratio of the brightness of the output in units of foot-lambert, compared to the illumination of the input in foot-candles. A typical value for a GEN III tube is 25,000 to 30,000 Fl/fc. A “tube gain” of 30,000 Fl/fc provides an approximate “system gain” of 3,000. This means that the intensified NVG image is 3,000 times brighter to the aided eye than that of the unaided eye.

GENERATION – The term “generation” is often used to describe the age of the technology used to manufacture the image intensifier tubes. There are currently three generations of tubes described below: Generation I. These intensifier tubes were developed in the 1960’s using vacuum tube technology. They use simple grid shaped electrodes to accelerate the electrons through the tube. They required a full moon to achieve an acceptable level of performance. This tube was characterized by excessive blooming and distortion from light sources in the field of view. GEN I tubes have a light amplification of only 1,000 times in comparison with GEN III tubes at 40,000 times. Operating life was only 2,000 hrs. Generation II (GEN II). These tubes were developed with 1970’s technology and incorporated the first microchannel plate (MCP) application to achieve brightness gain. These tubes could operate satisfactorily with one-quarter moon illumination and exhibit low distortion. They amplified light 20,000 times and had an average operating life of 2,500 hrs. Generation III (GEN III). Generation III tubes were developed in the 1990’s and use Gallium Arsenate (with even deeper sensitivity to the infrared spectrum) for the photocathode and a micro-channel plate for gain. The micro-channel plate is also coated with an ion barrier film to increase tube life. The GEN III tube provides very good to excellent low light level performance and can be used in illumination levels down to starlight only. The image is clean and with excellent contrast, and has a long tube life. The expected life span for the GEN III tube is estimated to be 10,000 hours of operation.

GOGGLE FORM FACTOR – The term “goggle form factor” refers to the general physical and mechanical characteristics of the goggles. Traditionally there have been and still are two basic goggle form factors, full face goggles and displaced goggles.

GOOD VISUAL ENVIRONMENT (GVE) – Night conditions such that the pilot has little difficulty using the NVG. Any scintillation or visual obscurations that may be present does not pose extra pilot workload.

HONEYCOMB – See Fixed-Pattern Noise.

ILLUMINANCE – Also referred to as illumination. The amount, ratio or density of light that strikes a surface at any given point.

IMAGE DISPARITY – This condition may exist when there is a difference in brightness between the two image intensifier assemblies within the same binocular.

IMAGE DISTORTION – This problem is more easily detected in high-light conditions. Image distortion is evidenced by vertical objects, such as trees or poles appearing to wave or bend when the user moves his head vertically or horizontally when looking through the goggles. Ground surfaces in the direction of hover may appear to swell or sink. Distortion does not change during life of an image intensifier. Limits on allowable distortion are an important part of performance specifications since excess distortion can interfere with viewing the image and thus with the operator's ability to perform necessary flight manoeuvres.

IMAGE INTENSIFIER – An electro-optic device used to detect and intensify optical images in the visible and near infrared region of the electromagnetic spectrum for the purpose of providing visible images. The image intensifier tube is the component of the NVG that actually performs the intensification process. The image intensifier is composed of the photo cathode, MCP, screen optic, and power supply. It does not include the objective and eyepiece lenses.

INCANDESCENT – Refers to a source that emits light based on thermal excitation, e.g. heating by an electrical current, resulting in a very broad spectrum of energy that is dependent primarily on the temperature of the filament.

INFRARED – That portion of the electromagnetic spectrum in which wavelengths range from 0.7 microns to 1 millimetre. This segment is further divided into near infrared (0.7 – 3.0 microns), mid infrared (3.0 – 6.0 microns), far infrared (6.0 – 15 microns), and extreme infrared (15 microns – 1 millimetre). A NVG is sensitive to near infrared wavelengths approaching 0.9 microns.

INTERPUPILLARY DISTANCE (IPD) – Interpupillary distance is the distance between the centers of the pupils of the eyes when the eyes are parallel. Adjustment provisions for variable IPD should be a feature of the NVG to allow the full image to be seen by the NVG user. The recommended range of adjustment should be at least 57 – 70mm to accommodate an estimated 90% of the potential user population. If no adjustment is provided, then the exit pupil must be large enough for the user to get a full field of view.

IRRADIANCE – The radiant flux density incident on a surface. For the purpose of this document the terms irradiance and illuminance shall be interchangeable.

LIGHT INTERFACE FILTER (LIF) – An optical filter that protects the NVG device and its user from some laser hazards. The LIFs, if installed, are mounted on an adapter attached to the end of the objective lens.

LINE PAIRS PER MILLIMETER (LP/MM) – Units used to measure image intensifier resolution. Usually determined from a 1951 Air Force Resolving Power test target. The target is a series of

different sized patterns composed of three horizontal and three vertical lines. The lines and spacing between lines in each of the different patterns differ in width; the narrower the width, the greater the resolution is needed to distinguish the lines in a given pattern. Human test subjects must be able to clearly distinguish all the horizontal and vertical lines of a particular pattern in order for an image intensifier to achieve the resolution represented by that pattern.

LUMEN – A measurement of luminous flux equal to the light emitted in a unit solid angle by a uniform point source of one candle intensity. The unit denoting the photons (light) perceivable by the human eye in one second.

LUMINANCE – The luminous intensity (reflected light) of a surface in a given direction per unit of projected area. This is the energy used by NVGs.

LUX – A unit measurement of illumination. The illuminance produced on a surface that is one-meter square, from a uniform point source of one candle intensity, or one lumen per square meter.

MICROAMPS PER LUMEN (A/LM) – The measure of electrical current (A) produced by a photocathode when it is exposed to a measured amount of light (lumens).

MICROCHANNEL PLATE (MCP) – A wafer containing between 3 and 6 million specially treated microscopic glass tubes designed to multiply electrons passing from the photo cathode to the phosphor screen in second and third generation intensifier tubes.

MICRON – A unit of measure commonly used to express wavelength in the infrared region; equal to one millionth of a meter.

NANOMETER (NM) – A unit of measure commonly used to express wavelength in the visible and near infrared region; equal to one billionth of a meter.

NAUTICAL TWILIGHT – The period of time, beginning in the morning and ending in the evening, when the center of the sun is 12 degrees below the horizon.

NEAR INFRARED – The shortest wavelengths of the infrared region, normally 750 to 2,500 nanometres. GEN II operates from around 440 to 950 nanometres.

NIGHT – The time between the end of evening astronomical twilight and the beginning of morning astronomical twilight.

NIGHT VISION DEVICE (NVD) – An electro-optical device used to provide a visible image using the electromagnetic energy available at night.

NIGHT VISION GOGGLE (NVG) – When referring to NVGs used for aviation purposes; a head-mounted, lightweight, self-contained binocular system consisting of two independent monocular intensifier tube assemblies.

OBJECTIVE LENS – The objective lens assembly collects the available light energy and focuses it on the photocathode (front end of the image intensifier tube). It is housed in an assembly that is used for distance focusing. A coating is placed on the inside portion of the lens that filters out specific wavelengths, thus allowing the use of properly modified interior lighting.

OPERATIONAL DEFECTS – These are defects that relate to the reliability of the image intensifier and are an indication of instability. If identified, they are an immediate cause for rejecting a particular NVG device.

OUTPUT BRIGHTNESS VARIATION – This condition is evidenced by areas of varying brightness in or across the image area. The lower contrasts do not exhibit distinct lines of demarcation nor do they degrade image quality. This condition should not be confused with shading.

PHOSPHOR SCREEN – The phosphor screen converts electrons into photons. A very thin layer of phosphor is applied to the output fiber optic system, and emits light when struck by electrons. See also Photocathode.

PHOTOCATHODE – The input surface of an image intensifier that absorbs light energy and in turn releases electrical energy in the form of an electron image. The type of material used is a distinguishing characteristic of the generations of image intensifiers.

PHOTON – A quantum (basic unit) of radiant energy (light).

PHOTOPIC VISION – Vision produced as a result of the response of the cones in the retina as the eye achieves a light adapted state (commonly referred to as day vision).

PHOTORESPONSE (PR) – See Photosensitivity.

PHOTOSENSITIVITY – Also called photocathode sensitivity or photoresponse. The ability of the photocathode material to produce an electrical response when subjected to light waves (photons). Usually measured in microamps of current per lumen (µA/lm). The higher the value, the better the ability to produce a visible image under darker conditions.

PILOT FLYING (PF) – The pilot who is in control of the aircraft either by operating the flight controls directly or through the autopilot.

PILOT NOT FLYING (PNF) – The pilot who is not operating the flight controls (see PF).

RADIANCE – The flux density of radiant energy reflected from a surface. For the purposes of this manual the terms radiance and luminance shall be interchangeable.

REFLECTIVITY – The fraction of energy reflected from a surface.

RESOLUTION – The ability of an image intensifier to distinguish between objects close together. Image intensifier resolution is measured in line pairs per millimetre (lp/mm) while system resolution is measured in cycles per milliradian (cy/mr). For any particular night vision system, the image intensifier resolution will remain constant while the system resolution can be affected by altering the objective or eyepiece optics, by adding magnification or relay lenses. Often the resolution in the same night vision device is very different when measured at the center of the image and at the periphery of the image.

SCINTILLATION – A faint, random sparking effect throughout the image area. Scintillation is a normal characteristic of microchannel plate image intensifiers and more pronounced under low light level conditions. Scintillation is sometimes called video noise.

SCOTOPIC VISION – That vision produced as a result of the response of the rods in the retina as the eye achieves a dark-adapted state (commonly referred to as night vision).

SIGNAL-TO-NOISE RATIO (SNR) – A measure of the light signal reaching the eye divided by the perceived noise as seen by the eye. A tube's SNR determines the low-light resolution of the image tube, therefore, the higher the SNR, the better the ability of the tube to resolve objects with good contrast under low light conditions. Because SNR is directly related to phosphor efficiency and MCP operating voltage, it is the best single indicator of image intensifier performance.

SITUATIONAL AWARENESS (SA) – Degree of perceptual accuracy achieved in the comprehension of all factors affecting an aircraft and crew at a given time.

SPATIAL FREQUENCY – The number of features or lines per unit of space.

STARLIGHT – The illuminance provided by the available (observable) stars in a subject hemisphere. The stars provide approximately 0.00022 lux ground illuminance on a clear night. This illuminance is equivalent to about one-quarter of the actual light from the night sky with no moon.

STEREOPSIS – Visual system binocular cues that are used for distance estimation and depth perception. Three dimensional visual perception of objects. The use of NVGs seriously degrades this aspect of near-depth perception.

TRANSMITTANCE – The fraction of radiant energy that is transmitted through a layer of absorbing material placed in its path.

ULTRAVIOLET (UV) – That portion of the electromagnetic spectrum in which wavelengths range between 0.1 and 0.4 microns.

UNAIDED – Term used to describe those times when NVGs are not being used (i.e. normal night vision is not being aided).

WAVELENGTH – The distance in the line of advance of a wave from any one point to the next point of corresponding phase; is used to express electromagnetic energy including IR and visible light.

WHITEOUT – A condition similar to brownout but caused by blowing snow.

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Flight crews	Low light level viewing	Procedures
Flight tests	Man machine systems	Simulation
Flight test methods	Methodology	Testing and assessment
Goggles		

14. Abstract

This AGARDograph presents a general summary of suggested Night Vision Goggle (NVG) testing methods and should be used as a framework for developing airborne and laboratory based experiments to evaluate equipment. The objective of this document is to provide an inventory of rules, standards, procedures, methods and means needed to test and evaluate night vision systems. In order to meet its objective, the scope of this AGARDograph is limited to the testing of night vision devices based on image intensification technology for use in rotorcraft. This AGARDograph includes sections covering the basic theory of the systems in use today, human vision and its relationship to the technology, general flight test methodology and an inventory of flight test techniques from NATO countries.

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